Passage of Radio-tagged Adult Pacific Lamprey at Yakima River Diversion Dams

2013 Annual Report
Phase 2: Sunnyside and Wapato Dams

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On the cover: A radio-tagged adult Pacific lamprey released in the Yakima River during the study. Photograph by Dave Herasimtschuk and Jeremy Monroe, © Freshwater Illustrated.

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PASSAGE OF RADIO-TAGGED ADULT PACIFIC LAMPREY AT YAKIMA RIVER DIVERSION DAMS: 2013 ANNUAL REPORT

Ann Grote, Mark C. Nelson, Cal Yonce, Andy Johnsen, Daniel J. Sulak, and R.D. Nelle

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Abstract- The Pacific lamprey *Entosphenus tridentatus* has declined across much of its range in the Pacific Northwest, including in the Yakima River. Several irrigation diversion dams may prevent or delay the upstream migration of adults in the Yakima River but the total impact on migration and spawning is not known. This report details the second of three phases of a radio-telemetry study designed to determine residence times, passage timing and durations, passage efficiencies, and passage routes of Pacific lampreys at diversion dams on the Yakima River. Eighty adult Pacific lampreys, collected at lower Columbia River dams during summer 2012, were radio-tagged and released downstream of Sunnyside Dam and downstream of Wapato Dam on August 27, 2012 and March 20, 2013. Overall passage success of lampreys that approached a dam was 68% at Sunnyside Dam and 82% at Wapato Dam. All passage events occurred from August-September 2012 and April-June 2013. At Sunnyside Dam, lampreys used the center (66%), right (28%), and left (3%) fishways while 3% used an unknown route. At Wapato Dam, lampreys used the left (41%), center (22%), and right (20%) fishways while 17% apparently passed via the dam face. Passage times in fishways at Sunnyside Dam averaged 0.9 hours (SD = 0.9; range = 0.1 to 3.3 hours) and at Wapato Dam averaged 1.6 hours (SD = 3.7; range = 0.1 to 23.5 hours). Two tagged lampreys were entrained in the Sunnyside Canal: one resided for 59 days and the other was not detected exiting the canal. One lamprey was entrained and resided in the Wapato Canal for 53 days before moving upstream. A substantial number of tagged lampreys entered and used Roza Wasteway #2, including 20 of 49 lampreys (41%) during the fall and 4 of 11 lampreys (36%) during the spring. Minimum known residence in the wasteway ranged from 1.4 to 324 days. Twelve tagged lampreys migrated to Roza Dam and six ascended the ladder to the salmon trapping facility where they spent from 1 to 26.5 days in the holding pen before descending the ladder, resulting in 0% passage efficiency at the dam. Six of ten lampreys (60%) passed Cowiche Dam with the uppermost detection at rkm 53 of the Naches River. Dam passage efficiencies were seasonally inverted at Phase 2 study dams relative to Phase 1 study dams: passage of fall-released fish was substantially higher than for spring-released fish at Sunnyside (96% fall, 33% spring) and Wapato (95% fall, 55% spring) compared to Wanawish (53% fall, 71% spring) and Prosser (50% fall, 45% spring). Seasonal effects at Yakima River diversion dams have the potential to exacerbate cumulative passage throughout the system. Reduced fall passage at the lower river dams (Wannawish and Prosser) may decrease the number of lampreys available to pass the upper river dams (Sunnyside and Wapato) in the fall when passage success at these facilities is highest.

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Introduction

The Pacific lamprey *Entosphenus tridentatus* is an anadromous fish native to the Columbia River Basin and many of its tributaries, including the Yakima River (Patten et al. 1970). Over the last decade the number of adult Pacific lampreys returning to the Yakima River has been minimal, with counts at Prosser Dam (river kilometer 75) ranging from 0 to 65 individuals per year (DART 2011). These low counts are consistent with the declines observed at Columbia River dams (Kostow 2002, DART 2011). Several factors including construction and operation of hydroelectric and diversion dams, river impoundment, water withdrawals, stream alteration, habitat degradation, elevated water temperatures, pollution, and ocean conditions have likely contributed to this decline (Luzier et al. 2011).

Mainstem Columbia River hydroelectric dams cause major delays and difficulties for the upstream migration of Pacific lampreys; telemetry studies of Pacific lamprey movements documented that less than 50% of tagged fish successfully passed upstream through the fishways (Moser et al. 2002a, Moser et al. 2002b, Johnson et al. 2009, Keefer 2009). Several diversion dams exist in the Yakima River Basin and may be impediments for adults migrating to suitable spawning areas. However, details on upstream migration, timing, spawning, and distribution of Pacific lamprey in the Yakima River are not well understood.

To better understand migrations dynamics, we began a multiyear study in 2011 investigating Pacific lamprey passage at diversion dams in the Yakima River basin. The objective of this multi-year radio telemetry study is to determine adult Pacific lamprey passage at the Yakima River diversion dams, including approach timing, residence time downstream of dams, passage routes, passage duration, total time spent at the dams, and migration rates between dams. In addition, areas where Pacific lamprey over-winter and spawn in the Yakima River will be located if possible. Information from this study will help guide management recommendations for improving passage at the dams in the Yakima River.

Results from Phase 1 of this study at Wanawish and Prosser dams indicated overall passage efficiencies of 62% and 48%, respectively, with lower passage rates during the fall (Johnsen et al., 2013). Only 7% of the lampreys released downstream of Wanawish Dam were documented passing Wapato Dam, the fourth dam on the Yakima River.

This annual report presents the results of Phase 2 of our study at Sunnyside and Wapato dams for the 2012 migratory year, from September 27, 2012 through August 31, 2013.

Background

Similar to summer steelhead *Oncorhynchus mykiss*, Pacific lamprey enter freshwater a year prior to spawning, migrate upstream to overwinter, and then access spawning tributaries or areas the following spring. Unlike many anadromous fishes, Pacific lampreys do not appear to home to their natal streams (Hatch and Whiteaker 2009, Spice et al. 2012), but instead may utilize the "suitable river strategy" in which returning adults are attracted to streams inhabited by larval lamprey or ammocoetes (Waldman et al.

2008). Recent genetic studies differ on whether Pacific lampreys are panmictic (Goodman et al. 2008, Docker 2010, Spice et al. 2012).

Adults typically return to the Columbia River from February to June (Kostow 2002) and begin to arrive at McNary Dam (67 kilometers downstream of the Yakima River confluence) in early June with the peak of migration in late July or early August (DART 2011). During a migratory year, lampreys are not observed at Prosser Dam until mid to late August and only a few are counted through the fall. Most of the returning adults are observed the following spring with the majority counted during April and May (DART 2011). However, radio telemetry studies conducted in tributaries such as the John Day River (Bayer et al. 2000), the Willamette River (Clemens et al. 2011), and the Methow River (Nelson et al. 2009) found that Pacific lamprey entered these spawning tributaries in late summer and completed about 85% of their migration to spawning areas before overwintering. Thus it appears that migration timing in the Yakima River differs from other Columbia River tributaries.

This shift may be related to temperature differences between the Yakima and Columbia rivers. During July and August, temperatures in the lower Yakima River are on average almost 4 °C higher than in the Columbia River (mean 23.8 °C vs. 20.0 °C, 2002 to 2009 data- USBOR 2011; DART 2011). This appears to create a thermal barrier that either encourages lampreys to migrate past the Yakima River and continue upstream in the Columbia River or discourages lampreys from entering the Yakima River until later in the fall after temperatures equilibrate. Elevated spring passage numbers at Prosser Dam suggest that lampreys may also be overwintering in the Columbia River and entering the Yakima River the following spring. Radio-tagged Pacific lampreys translocated to the Yakima River exhibited the same migratory behavior as those that entered the river naturally (Johnsen et al. 2011), supporting both the hypothesis of no natal homing and shifted migration timing within the Yakima River.

To evaluate seasonal effects on Yakima River lamprey migration, we designed our study to test passage at the dams during both the fall and spring. Accordingly, we tagged and released a portion of our study fish in the fall and held the others over winter before tagging and releasing them in the spring. This design was intended to mimic both the timing of the "natural" run and the condition of the lampreys during their migration in the Yakima River.

Methods

Study Area

The Yakima River flows for 344 km, from the headwaters at Keechelus Lake in the Cascade Mountains to the confluence with the Columbia River at river kilometer (rkm) 539, and drains an area of approximately 15,941 km^2 (Figure 1). Annual mean discharge at the Kiona Gage Station (rkm 48.1) is 3,479 cubic feet per second (ft^3/s) (range 1,293 – 7,055 ft^3/s), with the highest daily mean discharge of 59,400 ft^3/s recorded on December 24, 1933 and the lowest daily mean discharge of 225 ft^3/s recorded on April 4, 1977 (USGS 2011). The main tributaries include Satus Creek, Toppenish Creek, Naches River, Taneum Creek, Teanaway River, and Cle Elum River.

A complex irrigation network, managed in large part by the U.S. Bureau of Reclamation (USBOR), makes the Yakima River Basin one of the most intensely irrigated areas in the United States. Six lakes and reservoirs, with a total active storage capacity of 1.07 million acre-feet, hold the spring and summer snowmelt in the mountains for delivery to irrigation districts between April and October (Fuhrer et al. 2004). Surface water diversions are equivalent to about 60% of the mean annual stream flow from the basin (Fuhrer et al. 2004). In spring, the stream flow reflects the quantity of water stored in the mountain snowpack, while during the dry summer months it reflects the quantity of water released from the basin's storage reservoirs. During summer, return flows from irrigated land account for 50 to 70% of the flow in the lower Yakima River (Fuhrer et al. 2004).

Irrigation water is distributed throughout the network via rivers, creeks, and man-made canals. Irrigation diversion dams include Wanawish, Prosser, Sunnyside, Wapato, Roza, Town, and Easton on the Yakima River and Cowiche and Wapatox on the Naches River (Figure 1).

Fixed Stations

Fixed radio telemetry stations were set up at six diversion dams and at the outfall of a power plant return flow canal (Figure 2). The standard layout at a diversion dam consisted of long-range aerial antennas that monitored downstream of the dam, the face of the dam, and upstream of the dam. Short-range underwater antennas monitored pools at the entrance, middle, and exit of each fishway. Short-range, hanging, coaxial antennas were deployed above the waterline at at the intesections of the fishways and dam face where flow conditions or debris loads would have damaged underwater equipment. Aerial antennas were four element Yagi-type. Underwater and hanging antennas were constructed of coaxial cable with 100 mm of the inner wire bared at the end. Aerial antennas were mounted on masts; underwater antennas were suspended on chains; and hanging antennas were zip-tied to rails and posts.

Data logging telemetry receivers, (Lotek SRX-400A, Lotek SRX-600), equipped with an antenna switching unit (Lotek ASP 8), were housed in a metal box at each station (Lotek Wireless, Newmarket, Ontario). When available, AC power was used to charge the external 12v battery that powered the receiver at each diversion station. Solar panels were used as a back-up power system and as the primary power source at stations with no available AC power.

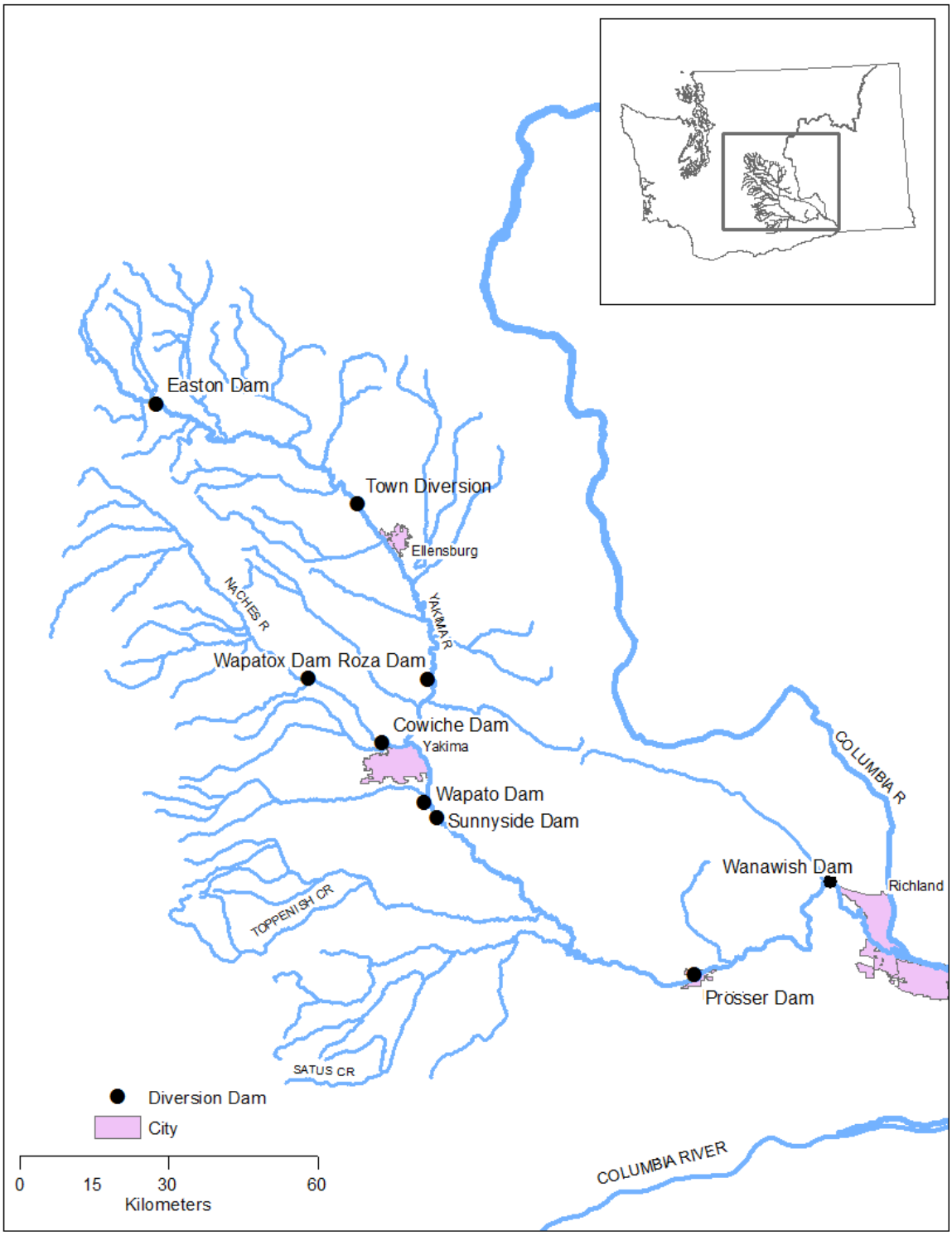

Figure 1. Map of the Yakima River watershed, showing the locations of the major diversion dams.

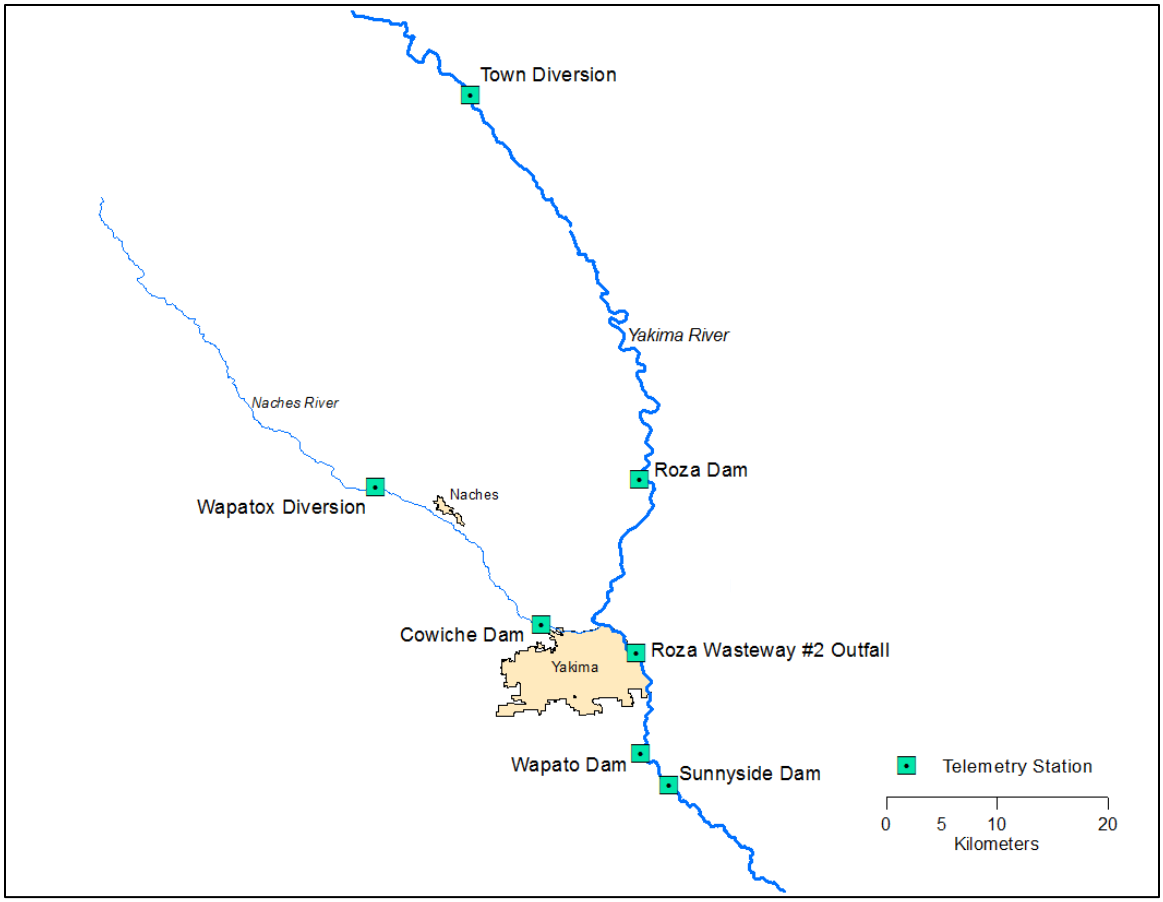

Figure 2. Map of the middle Yakima River basin showing the locations of fixed telemetry stations during 2012 and 2013.

The following illustrations of each dam and fishway were generated in Google SketchUp (version 8.016846) and are based on engineering drawings and construction blueprints obtained from the U.S. Bureau of Reclamation and on aerial photos. These illustrations depict the general layout of the fishways and thus omit screening and operational details.

Sunnyside Dam

Sunnyside Diversion Dam, located at rkm 167, was completed in 1907. It is a concrete ogee weir with embankment wing and a canal (1,320 ft^3/s capacity) on the left bank. The structural height is 2.4 m and the weir crest length is 152 m (USBOR 2011). Fish passage facilities consist of three stair step vertical slot ladders, one on each bank and one near the center of the dam (Figure 3). The left and right bank fishways have one high flow and one low flow gate. The center island has two high flow and two low flow gates; one located on each side.

The left bank fishway was equipped with one upstream aerial antenna and two downstream aerial antennas (combined as one unit, Figure 3). Underwater antennas were located in the entrance, center, and exit pools of the river left fish ladder. Hanging antennas monitored the sluiceway and the corner where the structure meets the face of the dam.

The center island fishway was equipped with a total of four aerial antennas: two antennas (combined as one unit) monitored downstream and two antennas monitored upstream on either side of the fishway (Figure 3). Underwater antennas were located in both entrance pools and a middle pool of the center fish ladder. Hanging antennas were placed in the corners of the island and the face of the dam.

The right bank fishway was equipped with three aerial antennas: one downstream, one across the face of the dam, and one upstream (Figure 3). Underwater antennas were located in the entrance, middle, and exit pools of the river right fish ladder. One hanging antenna monitored where the right bank structure and the face of the dam meet.

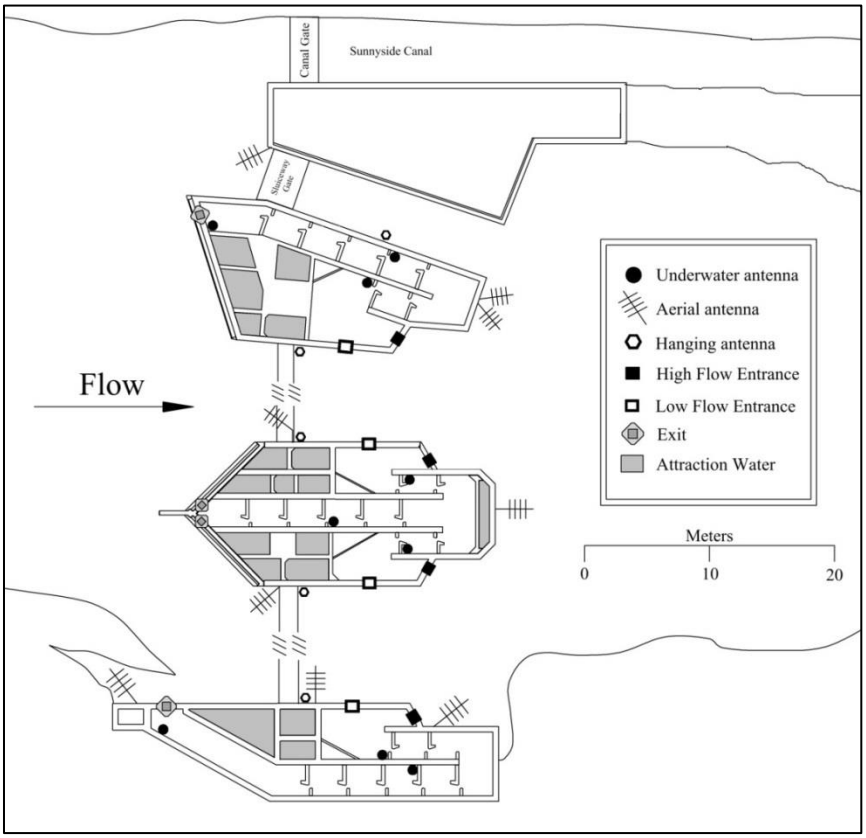

Figure 3. Locations of telemetry antennas on the river right, center and left bank fishways at Sunnyside Dam, 2012 to 2013.

Wapato Dam

Wapato Dam (rkm 171.5) consists of two separate structures in two channels connected by a natural island. The west channel has one fishway located on a center island structure with a diversion canal on the right bank. The east channel has fishways on both the center island structure and on the right bank. All the fishways consist of serpentine vertical slot pools with high and low flow gates in the entrance pool.

The east channel center island was equipped with three aerial antennas: one downstream, one upstream, and one monitoring the face on the river left side of the island. Underwater antennas were located in the entrance, middle, and exit pools of the fish ladder. A hanging antenna was located on the right side of the island near the face of the dam (Figure 4).

The right bank fishway was equipped with three aerial antennas: one facing downstream, one facing upstream, and one facing across the face of the dam. Underwater antennas were positioned in the entrance, middle, and exit pools of the fish ladder. One hanging antenna was placed in the corner where the face and left bank structure meet (Figure 4).

The west channel fishway was equipped with four aerial antennas: one oriented downstream, one oriented upstream, and two oriented across the face of the dam on either side of the center island. Underwater antennas were located in the entrance, middle, and exits pools of the fish ladder (Figure 5).

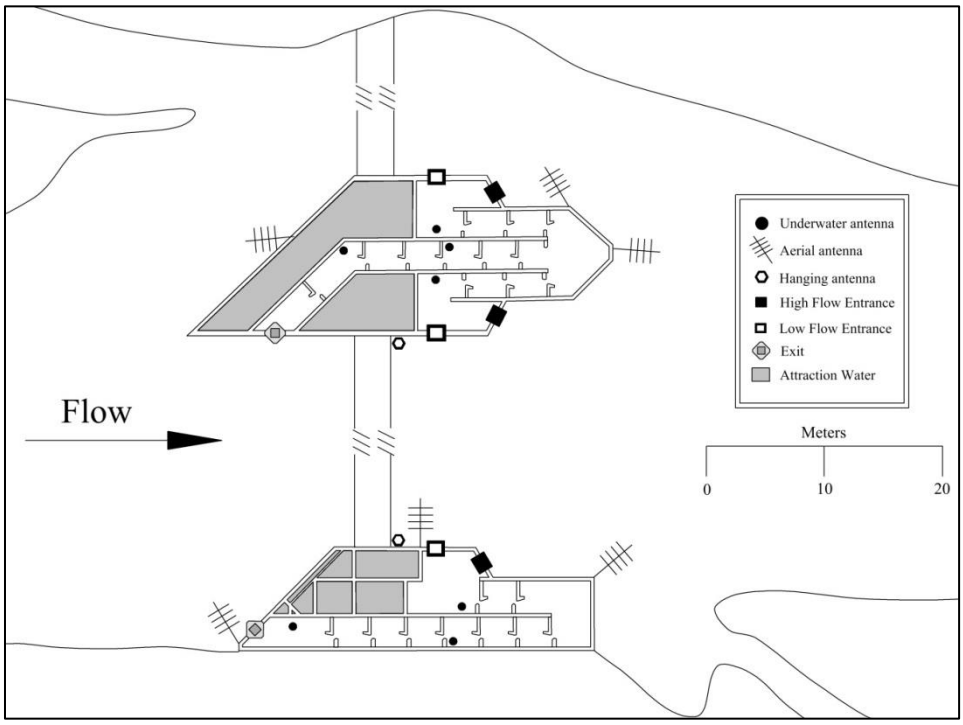

Figure 4. Locations of telemetry antennas on east channel fishways of Wapato Dam during 2012 and 2013.

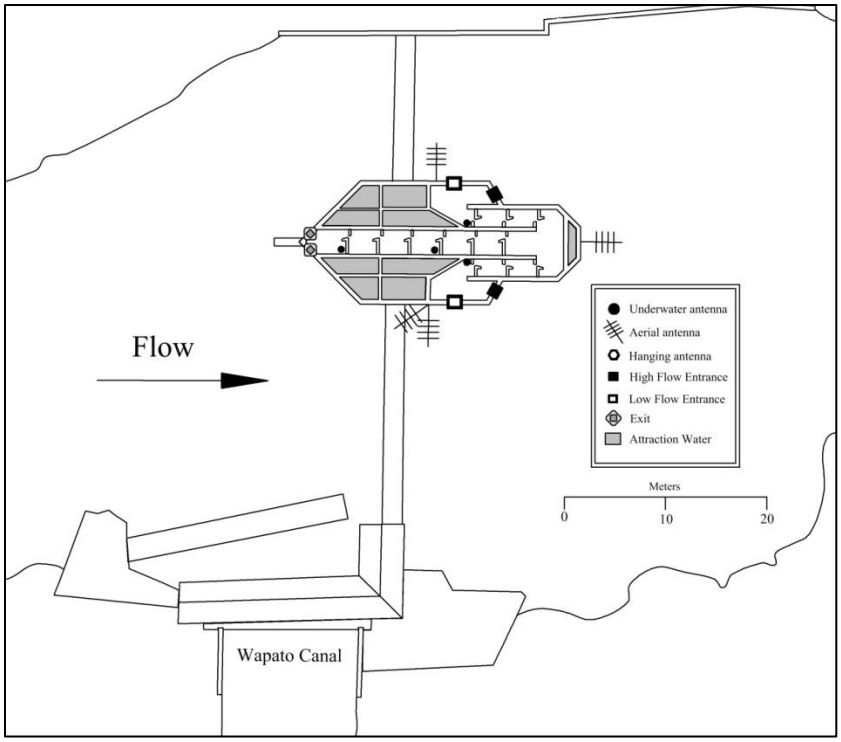

Figure 5. Locations of telemetry antennas on the west channel fishway at Wapato Dam during 2012 and 2013.

Roza Wasteway #2

The Roza Canal conveys water for both irrigation and hydropower. In 1959, the USBOR constructed the 12,937 kilowatt Roza Power Plant on a spur of the main diversion canal located approximately three miles northeast of the city of Yakima, WA. The Roza Power Plant return flow, known as Roza Wasteway #2, extends 1.4 km south of the Power Plant, and then rejoins the mainstem Yakima River at rkm 182 (Figure 6, Figure 18). The outfall of the Roza Wasteway #2 into the Yakima River is screened to exclude adult salmon.

The Roza Outfall radio telemetry station was located at the outfall fish screens. This station was equipped with a single aerial antenna facing upstream into the mainsteam Yakima River, and was AC powered. This station was run jointly with the Yakama Nation Fisheries Program.

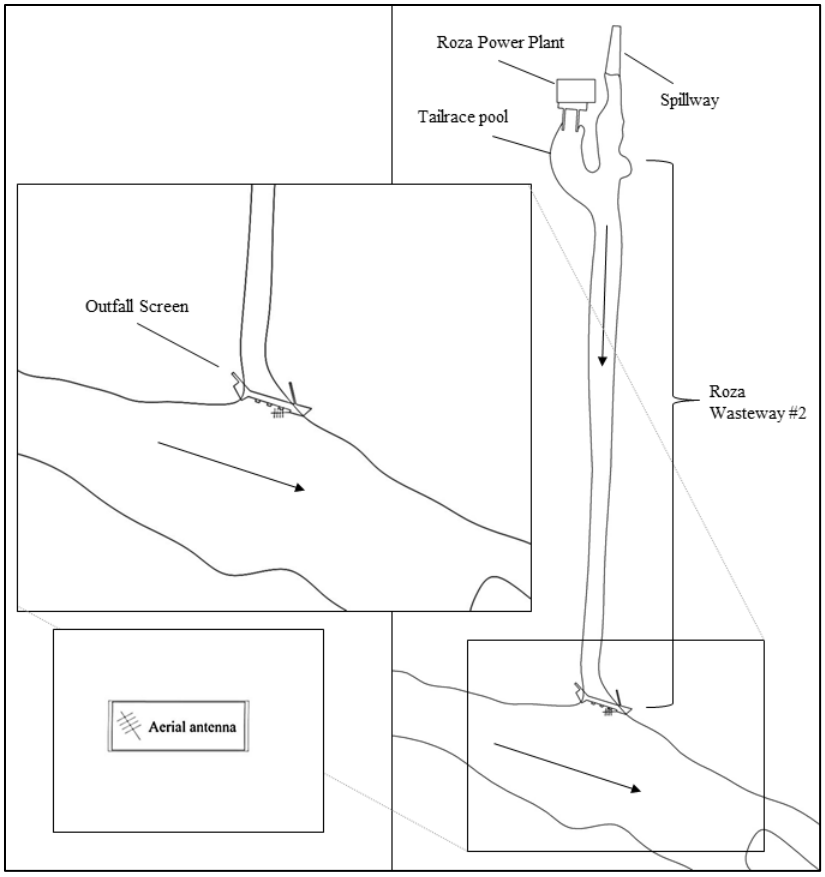

Figure 6. Location of the telemetry station at the outfall of Roza Wasteway #2 during 2012 and 2013.

Cowiche Dam

Cowiche Dam (rkm 6) on the Naches River is a concrete ogee spillway structure. It is approximately 65 m in length, with a 1.5 m crest, a 6.4 m ogee spillway, and a 6.4 m apron (George and Prieto 1993). A fish ladder consisting of vertical slot pools is located on the river left of the dam. A diversion canal and fish screen is located on the river right portion of the dam. For Phase 2 of this study, the left side of the dam was initially equipped with three aerial antennas: one downstream, one across the face of the dam, and one upstream. Three additional underwater antennas were installed in the fishway on February 26, 2013 (Figure 7). These new antennas were added in order to improve passage monitoring after several of the fall-release lampreys passed Cowiche Dam via unknown routes.

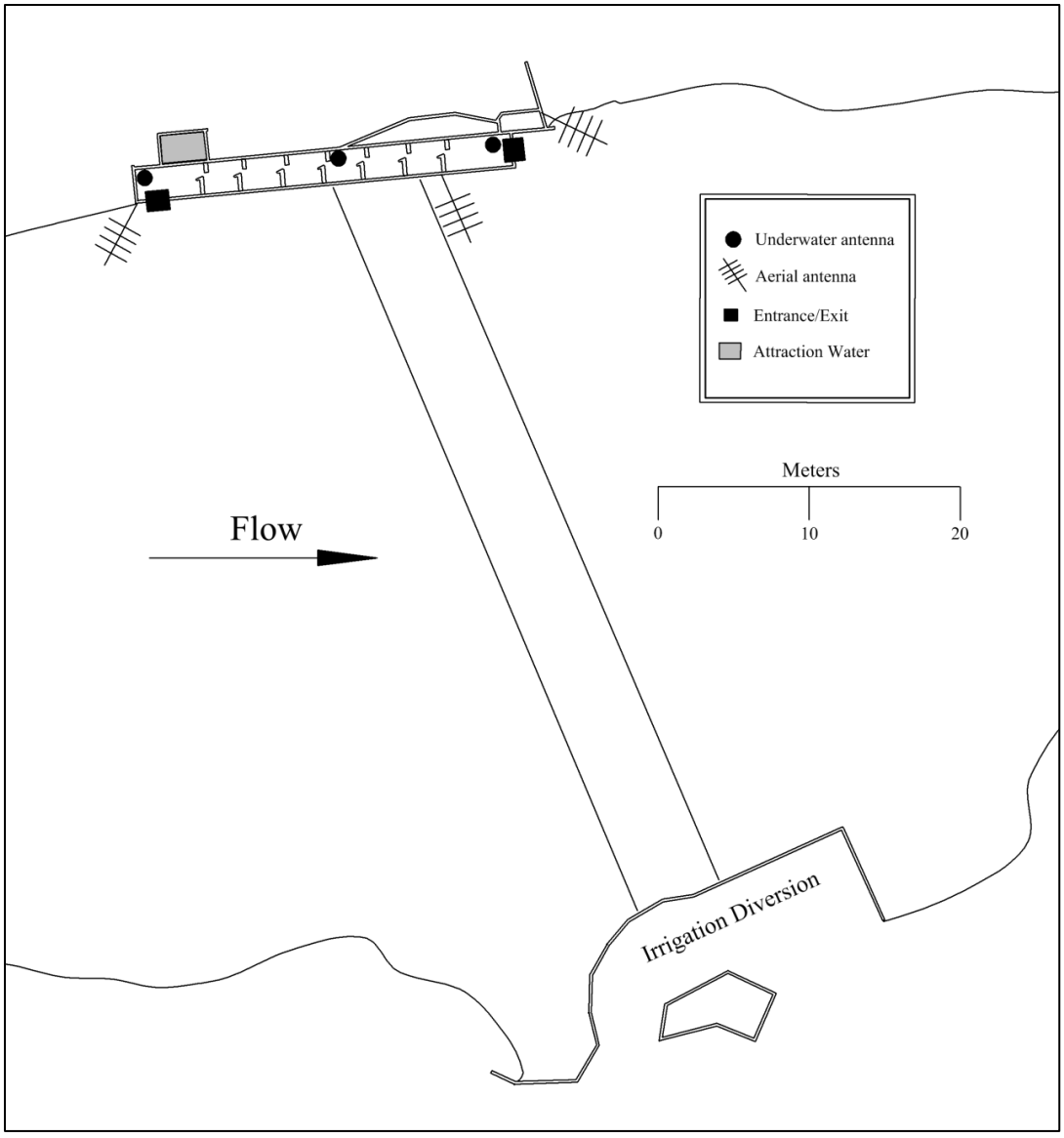

Figure 7. Locations of telemetry antennas at Cowiche Dam during 2012 and 2013.

Roza Dam

Roza Dam (rkm 205) was originally built in 1939 and is operated by the U.S. Bureau of Reclamation. It is a concrete weir with a movable crest structure. The dam stands 20.4 m tall and is 148 m in length (USBOR 2011). Water is diverted into an irrigation canal on the river right of the dam. The Roza Dam fishway is comprised of several structures, including a fishway entrance on river right, a fishway entrance on river left, a gallery passage connecting the right and left entrances, two notched pool and weir fish ladders on river left (high and low flow ladders), a gallery passage connecting the high flow ladder to the fish processing facility, and the fish processing facility (Figure 8).

During Phase 2 of this project, three telemetry stations (SRX 600) were deployed at Roza Dam (Figure 8). The river right station was equipped with three antennas, a downstream

aerial, a hanger at the river right fishway entrance, and an underwater antenna located partway between the fishway entrance and the cross-dam gallery. The river left station was initially equipped with four antennas, one downstream aerial, and underwater antennas at the river left fishway entrance, halfway up the high flow ladder, and at the ladder exit. Partway through the season, an additional underwater antenna was added halfway up the low water ladder to account for flow and maintenance conditions. The Roza fish facility station was equipped with two antennas: an underwater antenna located in the upper gallery at the entrance to the fish passage facility and an upstream aerial antenna monitoring the forebay. Roza Dam telemetry stations were plugged into AC power and did not include solar backup systems.

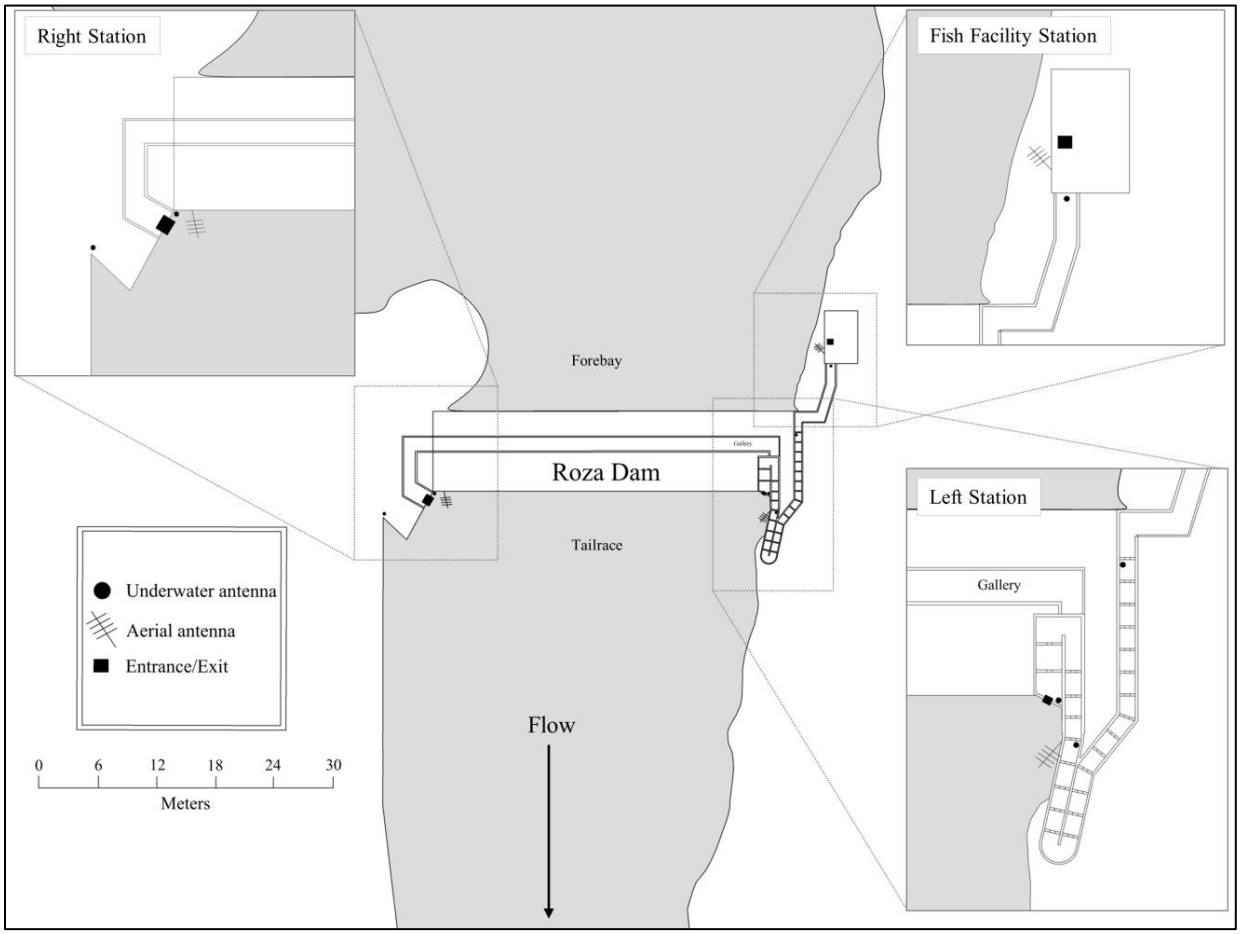

Figure 8. Locations of telemetry antennas at Roza Dam during 2012 and 2013.

Town Diversion

This gate station was Set up on April 5, 2013, at the Town Diversion of the Ellensburg Water Company. The Town Diversion site consisted of a single downstream aerial antenna and the receiver was plugged into AC power in the operations building.

Telemetry Data Analysis

For descriptive purposes, the definitions of *left* and *right* were referenced to the downstream or river flow direction, and applied to the river banks as well as the island fishways at the dams. *First approach* was defined as the first detection recorded on any antenna at a fixed telemetry station. *Below dam residence* was calculated as the elapsed time between the first downstream detection at the dam and either the first detection of entry into the fishway during a passage event, or the last detection before a fish moved downstream out of range of the receivers. *Fishway passage* was calculated as the elapsed time between the first fishway entrance detection and the last fishway exit detection during a passage event. In the event that an exit antenna detection was missing, the final corner face detection was substituted. *Dam passage efficiency* was defined as the number of lampreys that successfully passed the dam at least once divided by the number of lampreys that approached the dam (i.e., passage through a dam was only scored one time for each fish). *Above dam residence* was defined as the difference between the last fishway exit detection and the last upstream aerial antenna detection at the dam. *Roza Wasteway Canal Residence Time* was calculated as the sum of time elapsed between mobile tracking detections within the canal (representative of fish that stayed in the canal) or between mobile tracking detections in the canal and the first detection at Roza Outfall (representative of fish that left the canal).

Collection

Adult Pacific lampreys were supplied by the Yakama Nation Fisheries Program from lampreys collected at Bonneville Dam, The Dalles Dam, and John Day Dam on the lower Columbia River between June and August 2012. Fish were captured in funnel traps at the picketed leads of the fish counting stations on both sides of the dams and transported to the Yakama Nation Prosser Hatchery facility where they were help until tagging. All were injected with 0.15 cc of Oxytetracycline to prevent the spread of disease (Patrick Luke, Yakama Nation Fisheries Program, pers. comm.). Holding facilities consisted of flow-through metal stock tanks supplied with river and/or well water.

Radio Transmitter Implantation

Implantation surgeries took place in the spawning shed at the Yakama Nation Prosser Hatchery facility. The surgical procedure was modified from methods described in Moser et al. (2002a) and Nelson et al. (2007). Tools and transmitters were chemically disinfected with Benz-All®. Each lamprey was anesthetized in a bath of 80 mg/l tricaine methanesulfonate (MS-222) buffered with sodium bicarbonate to match the pH of the river water. After 8 to 10 minutes the fish was removed from the bath and total length (mm), interdorsal base length (mm), girth (mm), and weight (g) were measured and recorded. The lamprey was then placed on a cradle made from PVC pipe and the head and gills were immersed in a 15 L bath of 40 mg/l of buffered MS-222. Wet sponges were placed in the cradle to prevent the lamprey from sliding and to assist in incision placement. Using a number 12 curved blade scalpel, a 25 mm incision was made 1 cm lateral to the ventral midline with the posterior end of the incision stopping in line with the anterior end of the first dorsal fin. A catheter was inserted through the incision and out the body wall approximately 4 cm posterior to the incision. The antenna was threaded through the catheter and the individually coded radio transmitter was inserted into the incision. Lotek NTC-6-2 transmitters (9 x 30 mm, 4.3 g, 441 d battery life) were

implanted in fall release lampreys, and Lotek NTC-4-2L transmitters (8 x 18 mm, 2.1 g, 162 d battery life) were implanted into spring release lampreys. The incision was then closed with 3 to 4 braided absorbable sutures. Following tagging, the lamprey was immediately placed in a recovery bucket containing three gallons of aerated well water and transferred to the holding tanks.

Release

Release dates were selected to mimic the seasonal Pacific lamprey movements in the Yakima River system. Release sites were located downstream of Sunnyside Dam, between Sunnyside and Wapato dams, and upstream of Wapato Dam. Release sites were chosen by accessibility and relative close proximity to each dam. Individual lamprey were allocated to a release treatment by removing them from the holding tank at random. The code of each fish was then recorded prior to release.

Tracking

Fixed telemetry stations operated continuously and were downloaded on a weekly schedule. Test beacons were activated during downloads at each station to ensure the antennas and receivers were operating and recording properly. In addition to the data recorded at fixed stations, mobile tracking was conducted opportunistically to determine precise locations at the dams as well as approximate locations between the dams. Mobile tracking was conducted by foot, and truck.

Temperature

Stream temperatures were monitored at, Sunnyside, Wapato, Roza, and Cowiche dams. Electronic data loggers (HOBO® U22 Water Temp Pro v2, Onset Computer Corp.) were calibration checked for accuracy with an NIST-tested thermometer and only units that agreed to within 0.2 °C were deployed. The data loggers were housed in perforated PVC pipe (40 mm dia.) and tethered to wire cable suspended into the river from one fishway at each dam. Data loggers were programmed to record once every hour. Data were downloaded into a shuttle, offloaded, and saved to a desktop computer. Mean, minimum, and maximum daily water temperatures were calculated with the Hoboware® Pro software package.

Discharge

Stream discharge was obtained from the USBOR Pacific Northwest Region Hydromet website (http://www.usbr.gov/pn/hydromet/yakima/yakwebarcread.html). Average daily flow (QD) was queried for the Yakima River stations at Kiona (KIOW), Prosser (YRPW), and Parker (PARW). Discharge is reported in cubic feet per second (ft^3/s).

Velocity

Velocity data were not collected systematically in Phase 2. While Phase 1 velocity data indicated that high velocities occurred at Yakima River fishways, standardizing velocity sampling methods to collect quantitatively robust results proved to be beyond the scope of this study.

Results

Tagging

Tagging and release occurred in the fall 2012 and the spring 2013. For the fall releases, 45 adult Pacific lampreys were radio tagged August 2-3, 2012 (Table 1). Weights ranged from 367 to 886 g (mean 486 g), and total lengths from 675 to 768 mm (mean 675 mm, Figure 9). Girths ranged from 104 to 130 mm (mean 114 mm, Figure 10), and inter-dorsal base length ranged from 22 to 40 mm (mean 34 mm, Figure 11).

For the spring releases, 45 lampreys were tagged on February 20-22, 2013 (Table 2). Weights ranged from 258 to 550 g (mean 349 g), and lengths ranged from 530 to 695 mm (mean 585 mm). Girths ranged between 90 and 120 mm (mean 102 mm), and inter-dorsal base lengths ranged from 14 to 38 mm (mean 23 mm) (Figures 9 and 10).

Holding

Fish were held a minimum of three weeks after tagging before release. On March 15, 2013, one of the holding tanks overflowed, and 19 tagged lampreys escaped. Nine of the escaped fish were recovered by Yakama Nation Fisheries Program staff and lived, the other 10 were mortalities. The nine survivors were monitored for the remainder of the holding period (five days) and were released along with the remainder of the spring study fish. No evidence of an "escapee" effect on passage was observed, and data from these fish were included in all relevant calculations/analyses.

Releases

Fall release- A total of 45 tagged lampreys were released on August 27, 2012. Five were released from the head of the island 0.15 km upstream of Wapato Dam; 15 were released 2.6 km downstream of Wapato Dam (and 1.8 km upstream of Sunnyside Dam) on the left bank, and 25 were released 1.4 km downstream of Sunnyside Dam in the middle of the channel (Figure 12).

Spring release- A total of 35 Pacific lampreys were released on March 20, 2013 at the same locations used in the fall. Thirteen lampreys were released at the site between Wapato and Sunnyside dams, and 22 lampreys were released below Sunnyside Dam. No tagged lampreys were released above Wapato Dam because fewer tagged lampreys were available due to the mortalities incurred during holding.

Table 1. Morphometric data and release location of radio-tagged adult Pacific lampreys released in the Yakima River on August 27, 2012. Release locations are denoted as: AWD (above Wapato Dam), BWD (Below Wapato Dam), and Below Sunnyside Dam (BSD).

Code	Total Length (mm)	Weight (g)	Girth (mm)	Dorsal Base Length (mm)	Release Location
11	692	522	125	30	AWD
17	700	527	120	34	AWD
19	695	480	115	31	AWD
28	685	--	109	35	AWD
48	690	502	116	30	AWD
5	675	530	120	40	BWD
6	647	420	107	32	BWD
7	675	482	117	40	BWD
10	690	553	120	40	BWD
18	737	886	130	33	BWD
22	692	--	118	40	BWD
24	652	--	115	32	BWD
29	720	--	113	38	BWD
30	662	--	115	40	BWD
34	702	544	115	36	BWD
37	672	456	113	32	BWD
39	710	575	124	40	BWD
43	700	455	105	35	BWD
44	656	380	106	34	BWD
46	690	501	114	30	BWD
4	640	491	115	35	BSD
8	635	370	106	35	BSD
9	647	425	113	31	BSD
12	648	425	112	27	BSD
13	615	380	107	30	BSD
14	635	367	104	33	BSD
15	670	759	118	40	BSD
16	627	399	107	30	BSD
20	720	--	124	35	BSD
21	652	--	110	32	BSD
23	620	--	105	30	BSD
25	675	--	115	37	BSD
26	665	--	116	40	BSD
27	680	--	115	40	BSD
31	675	--	108	30	BSD
32	768	--	128	40	BSD
33	672	--	110	37	BSD
35	682	469	113	33	BSD
36	714	537	118	34	BSD
38	688	463	116	33	BSD
40	680	491	124	30	BSD
41	680	417	107	24	BSD
42	630	387	108	32	BSD
45	684	448	107	36	BSD
47	642	428	110	22	BSD

Table 2. Morphometric data and release location of radio-tagged adult Pacific lampreys released in the Yakima River on March 20, 2013. Release locations are denoted as: AWD (above Wapato Dam), BWD (Below Wapato Dam), Below Sunnyside Dam (BSD), and E/M (escaped/mortality)

Code	Total Length (mm)	Weight (g)	Girth (mm)	Dorsal Base Length (mm)	Release Location
52	572	295	96	27	BSD
53	545	305	100	16	BSD
54	560	302	99	24	BSD
55	580	359	107	26	BSD
56	655	--	116	38	BSD
57	635	--	109	33	BSD
58	662	--	109	29	BSD
59	583	--	95	25	BSD
60	605	372	102	20	BSD
65	582	348	99	19	BSD
68	542	296	95	30	BSD
72	610	329	97	31	BSD
75	695	550	120	35	BSD
76	602	381	105	27	BSD
79	587	342	100	27	BSD
80	565	386	111	18	BSD
82	610	422	112	28	BSD
83	560	310	95	22	BSD
85	610	450	113	20	BSD
89	545	302	103	16	BSD
90	600	388	107	20	BSD
93[a]	588	318	98	21	BSD
50	585	338	102	21	BWD
51	535	302	98	23	BWD
61	582	316	100	24	BWD
69	567	335	101	18	BWD
70	580	334	92	18	BWD
71	558	296	95	20	BWD
77	541	321	100	20	BWD
78	580	382	101	20	BWD
84	610	427	113	28	BWD
86	610	424	108	25	BWD
88	575	300	95	21	BWD
91	585	359	101	14	BWD
92	619	384	105	17	BWD
62	553	281	98	18	E/M
63	535	258	93	17	E/M
64	532	--	95	18	E/M
66	592	303	90	19	E/M
67	530	292	95	18	E/M
74	672	486	113	31	E/M
81	563	324	100	25	E/M
87	582	369	103	25	E/M
49	590	356	102	26	E/M
73	561	307	94	25	E/M

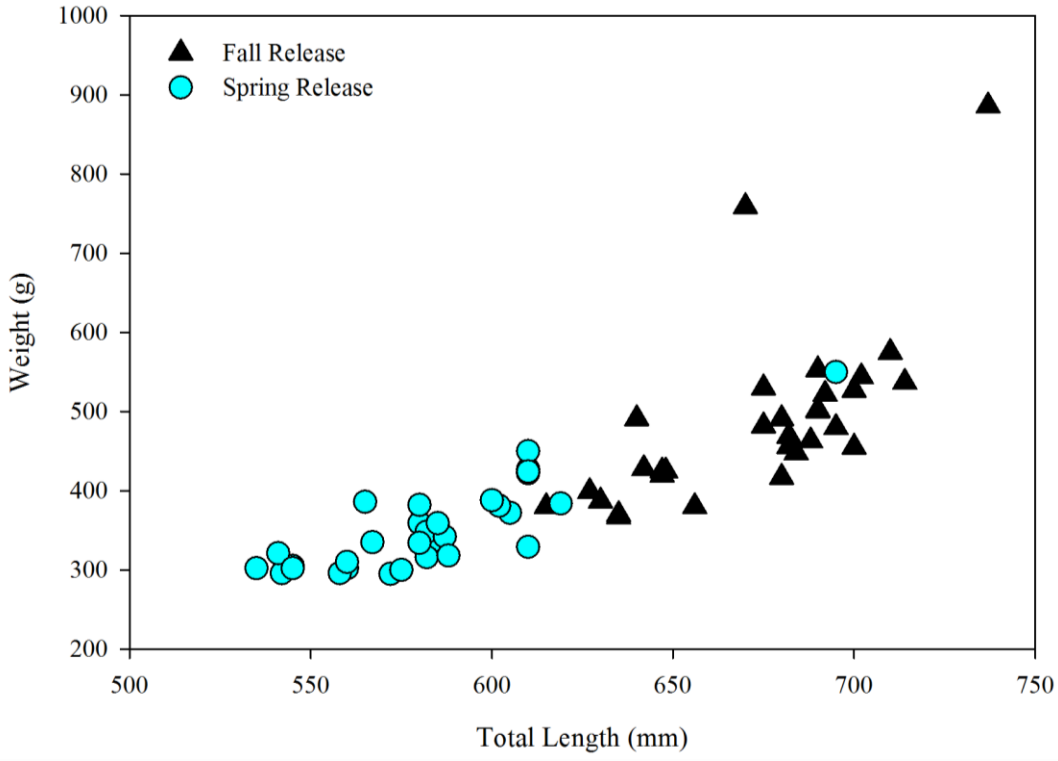

Figure 9. Weight versus total length of radio-tagged Pacific lampreys released into the Yakima River on September 27, 2012 and March 20, 2013.

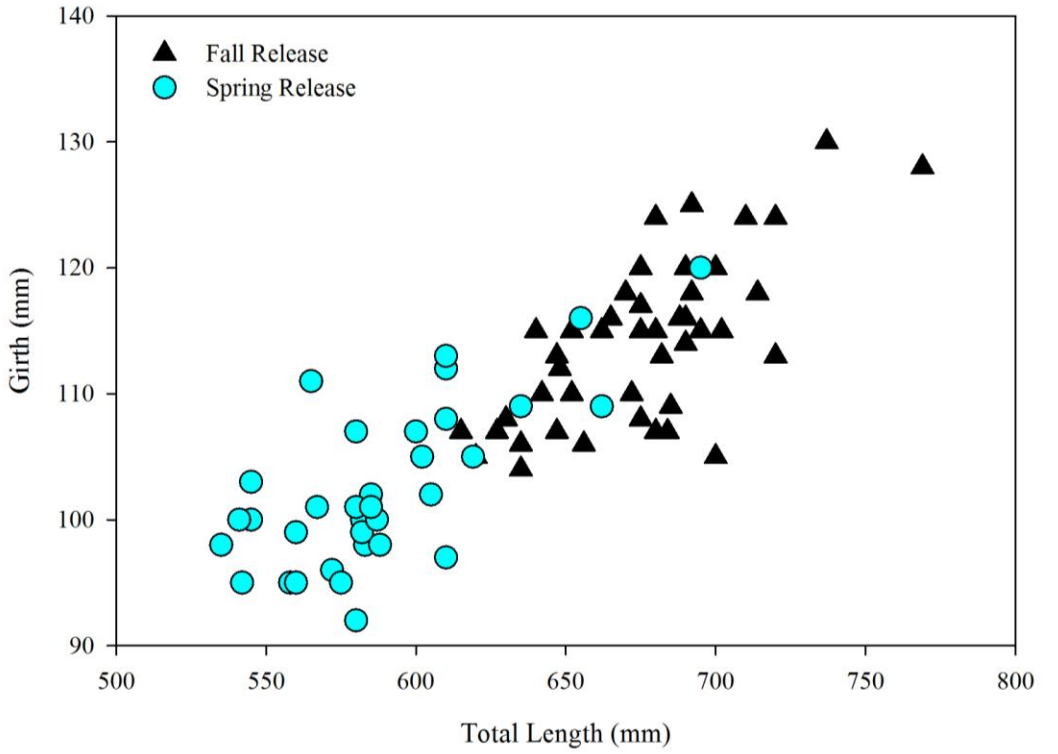

Figure 10. Girth versus total length of radio-tagged Pacific lampreys released into the Yakima River on September 27, 2012 and March 3, 2013.

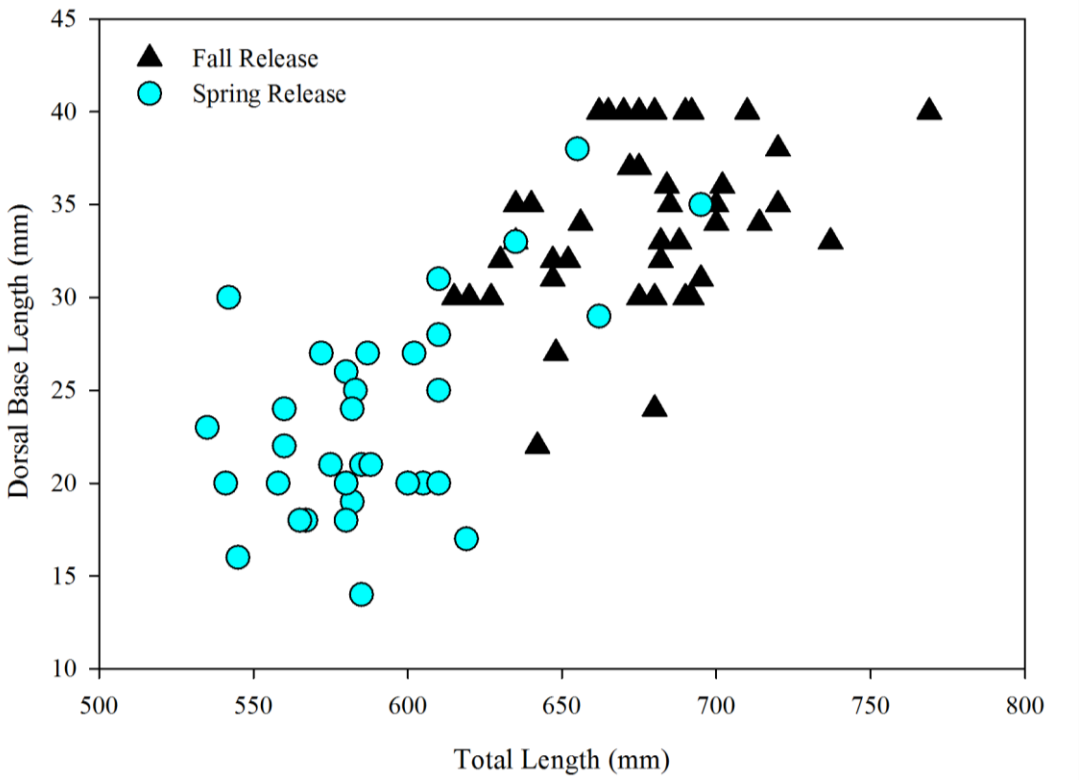

Figure 11. Inter-dorsal base length versus total length of radio-tagged Pacific lampreys released into the Yakima River on September 27, 2012 and March 3, 2013.

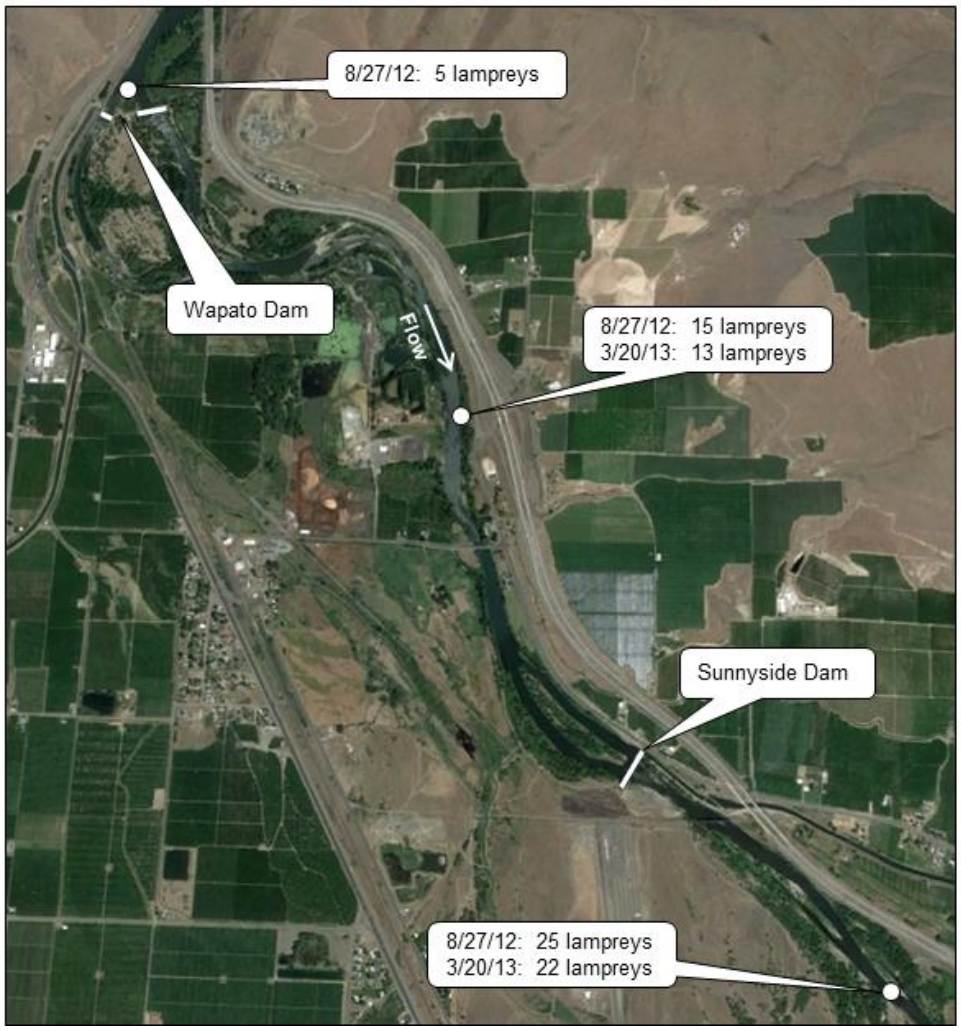

Figure 12. Release locations of radio-tagged adult Pacific lampreys in the vicinity of Sunnyside and Wapato dams on August 27, 2012 and March 20, 2013.

Movements

A total of 76 (95%) Pacific lampreys moved upstream from their release sites. Two moved downstream from their release sites and two never moved. Both of the stationary tags were assumed to be shed tags or mortalities. First approaches of a dam were made between August 27, 2012 and July 19, 2013. A total of four lampreys (codes 5, 18, 26, and 27) resided at the dams through the winter. The movements of radio-tagged lampreys at each dam are described in the following sections.

Sunnyside Dam

First approach of fall release- Twenty-five tagged lampreys were released downstream of Sunnyside Dam on August 27, 2012 and all 25 approached the dam on the day of release (Table 3). In addition, one tagged lamprey (code 19) released above Wapato Dam moved downriver past both Wapato and Sunnyside Dams, and approached Sunnyside Dam from downstream on May 8, 2013.

First approach of spring release- Tagged lampreys were released downstream of Sunnyside Dam on March 20, 2013 (n = 22). Twenty-one of these fish were detected approaching the dam. Detections of first approach of individuals at the dam ranged from March 20 to April 7, 2013.

Below dam residence- Residence times were calculated for all lampreys that were released below, and approached Sunnyside Dam. Below dam residence times ranged from 30 seconds to over 363 days (Table 3). Fish that successfully passed the dam exhibited shorter below dam residence times than those that did not, and lampreys that passed in the fall exhibited shorter residence times that those that passed in the spring (Table 4). One lamprey (code 19) was released above Wapato dam on August 27, 2012 and moved downstream over Wapato Dam on August 28, 2012. By April 8, 2013, this lamprey moved downstream over Sunnyside Dam. It later approached Sunnyside Dam, and passed upstream on May 8, 2013. This lamprey was excluded from the residence time analysis because it was not a part of the original treatment group released below Sunnyside Dam.

Two lampreys overwintered at the dam, one downstream (code 27) and one upstream (code 26) of the structure. Although it entered the ladders at Sunnyside right and Sunnyside left, code 27 did not pass the dam and was detected in the vicinity of the dam for over a year. During this time it is likely that the tag was either shed or the fish died. Code 26 passed the dam by September 30, 2012 but remained above Sunnyside until March 14, 2013 when is resumed upstream migration and was detected at Wapato five days later.

Both lampreys that overwintered below Sunnyside Dam were likely inactive for some period during the winter. However, during the overwinter period they stayed within range of the telemetry station and were detected (whether there were actively moving or not) on multiple antennas simultaneously. With continuous detections on multiple antennas over a period of months, we were unable to determine when lamprey became inactive, and the onset and duration of overwintering behavior is unknown.

Table 3. Sunnyside Dam approach and residence data: first and last detection dates and below dam residence times of adult radio-tagged Pacific lampreys released in fall 2012 and spring 2013.

Code	1st Detection Date	Last Detection Date	Days	Pass Dam?
20	08/27/12 15:05	08/27/12 21:33	0.27	Yes
33	08/27/12 15:05	08/29/12 02:22	1.47	Yes
13	08/27/12 16:06	08/27/12 21:08	0.21	Yes
41	08/27/12 16:18	08/27/12 16:47	0.02	Yes
8	08/27/12 16:25	08/27/12 20:46	0.18	Yes
40	08/27/12 16:35	08/29/12 01:21	1.37	Yes
23	08/27/12 16:39	08/30/12 00:40	2.33	Yes

Table 3 Continued

Code	1st Detection Date	Last Detection Date	Days	Pass Dam?
36	08/27/12 20:21	09/04/12 20:47	8.02	Yes
9	08/27/12 20:30	08/31/12 01:23	3.20	Yes
12	08/27/12 20:31	08/27/12 21:10	0.03	Yes
27	08/27/12 20:43	08/25/13 16:56	362.84	No
4	08/27/12 20:45	08/31/12 00:49	3.17	Yes
14	08/27/12 20:52	08/27/12 21:03	0.01	Yes
31	08/27/12 20:58	08/27/12 20:59	0.00	Yes
47	08/27/12 21:07	08/31/12 21:48	4.03	Yes
42	08/27/12 21:08	08/28/12 04:24	0.30	Yes
32	08/27/12 21:12	09/04/12 00:42	7.15	Yes
15	08/27/12 21:15	08/27/12 22:30	0.05	Yes
45	08/27/12 21:15	08/31/12 04:27	3.30	Yes
38	08/27/12 21:18	08/27/12 21:49	0.02	Yes
35	08/27/12 21:19	08/27/12 21:52	0.02	Yes
25	08/27/12 21:24	08/27/12 21:55	0.02	Yes
21	08/27/12 21:35	08/27/12 22:06	0.02	Yes
26	08/27/12 21:41	08/30/12 18:49	2.88	Yes
16	08/27/12 22:01	08/28/12 03:02	0.21	Yes
80	03/20/13 12:21	08/21/13 07:38	153.80	No
55	03/20/13 12:21	04/02/13 20:48	13.35	Yes
75	03/20/13 15:21	04/02/13 01:10	12.41	Yes
83	03/20/13 15:42	05/24/13 21:10	65.23	No
58	03/20/13 16:02	06/19/13 09:57	90.75	No
59	03/20/13 16:38	07/16/13 01:43	117.38	No
52	03/20/13 16:45	05/08/13 22:16	49.23	Yes
65	03/20/13 20:16	05/12/13 05:50	52.40	No
79	03/20/13 21:09	05/20/13 00:18	60.13	Yes
82	03/20/13 21:27	07/07/13 04:53	108.31	No
89	03/20/13 21:31	05/06/13 16:43	46.80	No
93	03/20/13 21:33	--	--	Yes
72	03/20/13 21:50	06/07/13 09:53	78.50	No
56	03/20/13 22:07	07/25/13 04:42	126.27	No
85	03/20/13 23:09	05/06/13 01:55	46.12	Yes
90	03/21/13 02:05	05/15/13 22:20	55.84	No
54	03/21/13 08:36	04/25/13 22:58	35.60	No
57	03/30/13 20:41	06/02/13 23:21	64.11	No
60	04/01/13 01:04	05/21/13 17:38	50.69	No
76	04/02/13 22:40	04/20/13 03:37	17.21	Yes
68	04/07/13 14:55	08/08/13 19:14	123.18	No

Table 4. Below dam residence summary for radio-tagged Pacific lampreys released below Sunnyside Dam in fall 2012 and spring 2013.

Release	Passage success	*n*	Duration (days)	Mean (days)	Median (days)	SD (days)
Fall	Yes	24	0.00 - 8.02	1.59	0.24	2.28
	No	1	362.84	362.84	362.84	--
Spring	Yes	7	12.41 – 60.13	33.07	31.66	21.12
	No	15	35.59 - 153.80	86.34	78.50	26.89

Dam passage efficiency and Fishway passage - Forty-seven tagged lampreys approached Sunnyside Dam, and 32 of these successfully passed upstream, resulting in an overall dam passage efficiency of 68% (Table 5). Twenty-six fall-release lampreys approached the dam, and 25 of these passed (96%). Twenty-two of the fall-release lampreys passed in August 2013, within 4.5 days of release. Two fall-release lampreys passed in early September 2012, and one passed in May 2013 after falling back over both Sunnyside and Wapato dams.

Dam passage efficiency was not as high for the spring release lampreys, as 21 approached the dam only seven passed (33%). Spring-release lampreys did not initiate passage as rapidly as the fall-release; successful passage events began on April 2 (13 days after release), and continued through July 2013.

Lampreys used the right (28%), center (66%), and left (3%) fishways to pass Sunnyside Dam. The remaining 3% of passage events occurred via unknown routes, where lampreys may have climbed the dam face or moved through a ladder when receivers were not operational.

All Sunnyside Dam ladder passage events occurred in less than 3.5 h (Table 5). Mean passage times were similar across seasons (fall: 1.07 hr, spring: 1.00 hr), and locations (right: 0.97 hr, center: 1.11 hr). The left fishway passed a single lamprey in 0.55 hr. Passage times were not calculated for the fish that passed via an unknown route.

Table 5. Sunnyside Dam passage data: passage routes, dates of entry, exit, and total time in fish ladder, and daily mean water temperature for radio-tagged adult Pacific lampreys from August 2012 to August 2013.

Code	Release Site/Period	Passage Route	Entered Ladder	Exited Ladder	Time in Ladder (hr)	Temp °C
41	BSD/Fall	C. Ladder	08/27/12 16:47	08/27/12 17:19	0.53	18.0
8	BSD/Fall	C. Ladder	08/27/12 20:46	08/27/12 22:42	1.93	18.0
31	BSD/Fall	C. Ladder	08/27/12 20:59	08/27/12 21:58	0.98	18.0
14	BSD/Fall	C. Ladder	08/27/12 21:03	08/28/12 00:10	3.12	18.0
13	BSD/Fall	C. Ladder	08/27/12 21:08	08/27/12 23:57	2.81	18.0
12	BSD/Fall	R. Ladder	08/27/12 21:10	08/27/12 22:01	0.84	18.0
20	BSD/Fall	C. Ladder	08/27/12 21:33	08/27/12 22:31	0.97	18.0
38	BSD/Fall	R. Ladder	08/27/12 21:49	08/27/12 22:06	0.29	18.0
35	BSD/Fall	C. Ladder	08/27/12 21:52	08/28/12 00:20	2.47	18.0
25	BSD/Fall	C. Ladder	08/27/12 21:55	08/27/12 22:21	0.43	18.0
21	BSD/Fall	C. Ladder	08/27/12 22:06	08/27/12 22:43	0.61	18.0
15	BSD/Fall	C. Ladder	08/27/12 22:30	08/27/12 23:05	0.59	18.0
16	BSD/Fall	C. Ladder	08/28/12 03:02	08/28/12 03:18	0.27	18.2
42	BSD/Fall	C. Ladder	08/28/12 04:24	08/28/12 05:11	0.77	18.2
40	BSD/Fall	R. Ladder	08/29/12 01:21	08/29/12 01:53	0.54	17.5
33	BSD/Fall	C. Ladder	08/29/12 02:22	08/29/12 05:41	3.32	17.5
23	BSD/Fall	C. Ladder	08/30/12 00:40	08/30/12 01:53	1.22	17.4
26	BSD/Fall	R. Ladder	08/30/12 18:49	08/30/12 21:01	2.19	17.4
4	BSD/Fall	C. Ladder	08/31/12 00:49	08/31/12 01:12	0.39	17.8
9	BSD/Fall	C. Ladder	08/31/12 01:23	08/31/12 01:26	0.04	17.8
45	BSD/Fall	C. Ladder	08/31/12 04:27	08/31/12 04:28	0.01	17.8
47	BSD/Fall	C. Ladder	08/31/12 21:48	08/31/12 22:51	1.06	17.8
32	BSD/Fall	C. Ladder	09/04/12 00:42	09/04/12 00:46	0.06	16.9
36	BSD/Fall	C. Ladder	09/04/12 20:47	09/04/12 20:54	0.11	16.9
75	BSD/Spring	R. Ladder	04/02/13 01:10	04/02/13 02:19	1.15	10.4
55	BSD/Spring	R. Ladder	04/02/13 20:48	04/02/13 22:52	2.07	10.4
76	BSD/Spring	R. Ladder	04/20/13 03:37	04/20/13 04:18	0.68	9.8
85	BSD/Spring	C. Ladder	05/06/13 01:55	05/06/13 03:31	1.59	12.0
19	AWD/Fall	R. Ladder	05/08/13 15:00	05/08/13 15:46	0.77	12.4
52	BSD/Spring	R. Ladder	05/08/13 22:16	05/08/13 22:29	0.22	12.4
79	BSD/Spring	L. Ladder	05/20/13 00:18	05/20/13 00:51	0.55	12.8
93	BSD/Spring	Right face	--	--	--	--

Discharge- Pacific lampreys passed Sunnyside Dam at a variety of discharge levels (Figure 13). Those passing in the fall did so at relatively low flows between 655 and 965 ft^3/s. Those passing during the spring months did so at widely varying flows between 2,500 and 8,100 ft^3/s. The majority of passage events, especially in the spring, occurred during periods of increasing discharge (Figure 13).

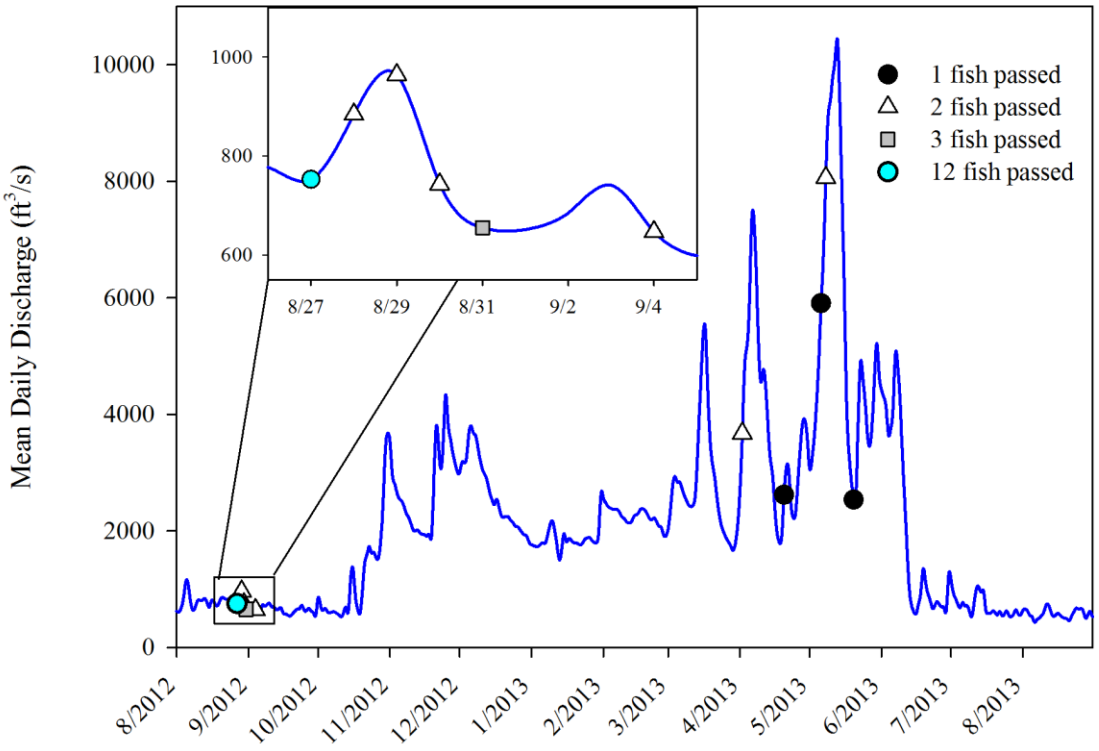

Figure 13. Mean daily discharge and passage timing of radio-tagged lampreys at Sunnyside Dam on the Yakima River, August 2012 through August 2013.

Temperature- Water temperatures of the Yakima River were recorded at Sunnyside Dam between August 1, 2012 and August 31, 2013 (Figure 14). Daily averages varied from 0 to 21 °C. Lamprey passage occurred during daily mean temperatures of 10.4 to 18.2 °C, with fall passage events occurring at warmer temperatures than spring passage events. In the fall, water temperatures rapidly declined below 16.9 °C after the last lamprey passed the dam and movements below the dam generally ceased for the remainder of the fall. In the spring, passage events resumed at temperatures greater than 9.7 °C. Spring passage events occurred at local temperature maxima, when average daily temperatures were transitioning from increasing to decreasing.

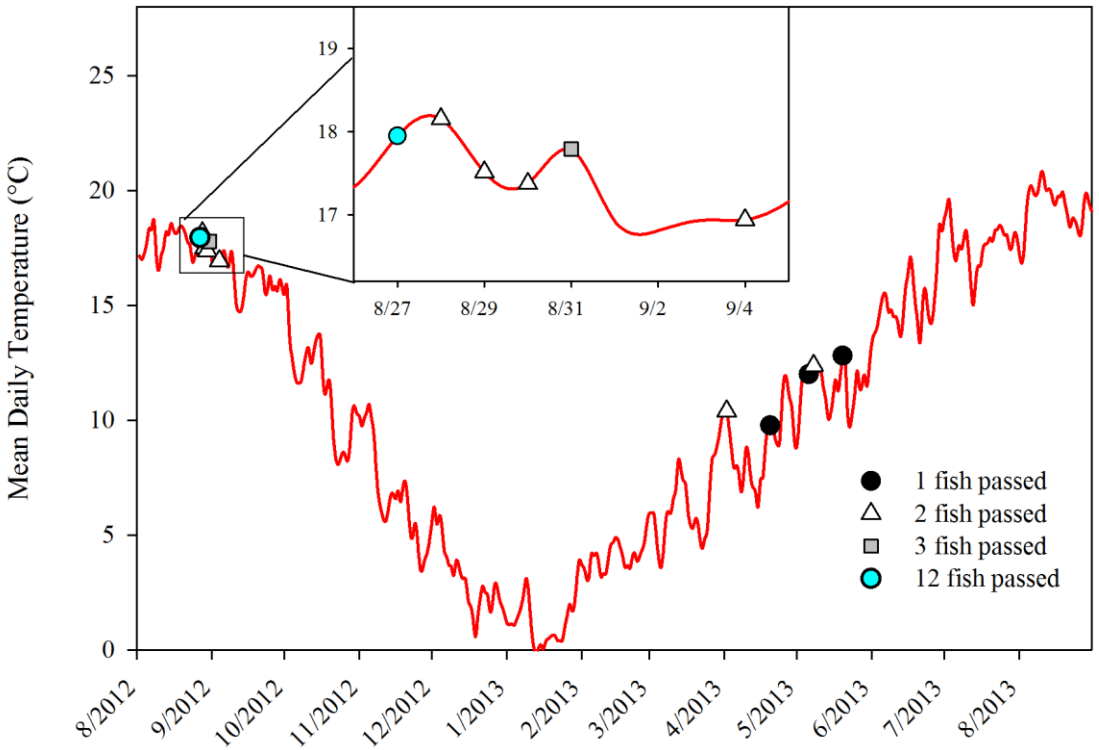

Figure 14. Mean daily water temperatures and passage timing of radio-tagged lampreys at Sunnyside Dam on the Yakima River, August 2012 through August 2013.

Above dam residence- Twenty-two of the 32 lamprey that passed Sunnyside dam moved rapidly upstream, leaving the upstream detection zone less than 1.5 h after exiting the fishways. Four of the Sunnyside lampreys exhibited an intermediate above dam residence period that lasted from 0.7 to 6.4 d. These four were detected on both the upstream aerial antennas at Sunnyside and the downstream and face antennas at Wapato, indicating that they moved back and forth between the dams after passing Sunnyside. One fall-release fish passed the Sunnyside ladder and overwintered in range of the upstream antenna array, resulting in an above dam residence time of 196.0 days.

Sunnyside Diversion Canal residence-Two tagged lampreys resided in the Sunnyside Canal upstream of the fish screen structure. One lamprey (code 79) was released downstream of the dam and one (code 18) was released upstream of the dam. Code 79 passed through the left fish ladder on May 20, 2013 and became entrained in the irrigation canal, and was located 30 meters downstream of the canal headgate on June 7 and 11, 2013. Code 79 resided in the canal for at least 41 to 59 d. It was last detected on the Sunnyside Dam antenna array on July 18, 2013, before it moved upstream and was detected on the Wapato Dam array on the following day. Code 18 was released between Sunnyside Dam and Wapato Dam at 15:46 on August 27, 2012 and almost immediately moved downstream as it was detected approaching Sunnyside Dam at 19:03 later that day. Although it was detected upstream of the dam until August 28, 2012 at 12:07, it is

unclear from the detection history whether the lamprey passed over the dam or entered the canal at that time. Truck-based tracking conducted in April and May 2013 indicated code 18 was in the Yakima River downstream of the dam but that conclusion was based on coarse signal vector direction and not foot-based tracking. It was recorded on the downstream antenna arrays but it was determined on June 7, 2013 that the fish was at the trash rack in the canal. Code 18 was not tracked in any of the ladders so if it had passed upstream of the dam the route was unknown. The most likely scenario of canal entrainment is that code 18 entered the canal as it moved downstream from its release location. It is also possible it entered the canal at the screening structure through the fish bypass system of primary and secondary return pipes. Code 18 was still in the canal when the tag battery expired on August 18, 2013.

Wapato Dam

First approach of fall release- On August 27, 2012, 15 tagged lampreys were released downstream of Wapato Dam and 12 of these eventually approached the dam (Table 6). First approaches at Wapato Dam occurred on the night of the release, when eight tagged lampreys moved upstream to the dam. Four more lampreys approached the dam over the next 10 days, with all fish having approached by September 7, 2012. The three fish that did not approach moved downstream over Sunnyside Dam: one tag was recovered downstream of the Sunnyside left station, one fish was detected in the Sunnyside Diversion Canal (code 18, see *Sunnyside Diversion Canal residence*), and one resided below Sunnyside Dam for several months.

First approach of spring release- On March 20, 2013, 13 tagged lampreys were released downstream of Wapato Dam and 12 of these fish were eventually detected approaching the dam (Table 6). Initial approaches in the spring occurred from March 21 to April 3, 2013, and no fish approached the dam on the evening following release. The one fish that did not approach Wapato Dam remained at the release site downstream of the dam, where it was detected through July 2013. It is likely that this was a shed tag or mortality.

Below dam residence- Lampreys that successfully passed the dam exhibited shorter below dam residence times than those that did not, and fish that passed in the fall exhibited shorter residence times than those that passed in the spring (Table 7). Residence time below Wapato Dam ranged from less than 2 h to more than 154 days (Table 6).

Table 6. Wapato Dam approach and residence data: first and last detection dates and total number of days that adult radio-tagged Pacific lampreys resided below Wapato dam before initiating a successful passage event or moving downstream, August 2012 through August 2013.

Code	1st Detection Date	Last Detection Date	Days	Pass Dam?
44	08/27/12 21:44	08/29/12 00:24	1.1	Yes
29	08/27/12 21:51	08/27/12 23:48	0.1	Yes
46	08/27/12 21:55	08/28/12 00:50	0.1	Yes
6	08/27/12 22:06	08/28/12 02:22	0.2	Yes
39	08/27/12 22:21	08/28/12 01:59	0.2	Yes
43	08/27/12 22:39	08/28/12 04:45	0.3	Yes
7[a]	08/27/12 23:00	--	--	Yes
24	08/28/12 00:55	08/31/12 01:26	3.0	Yes
30	08/28/12 21:32	08/29/12 00:18	0.1	Yes
37	08/31/12 22:41	09/01/12 01:57	0.1	Yes
10	09/05/12 21:40	--	--	Yes
22	09/07/12 22:03	09/10/12 00:51	2.1	Yes
78	03/21/13 00:27	05/16/13 23:21	57.0	No
84	03/21/13 02:23	08/22/13 22:46	154.8	No
77	03/26/13 21:55	03/31/13 22:54	5.0	Yes
88	03/31/13 22:35	04/01/13 21:21	0.9	Yes
61	04/01/13 21:56	04/02/13 22:01	1.0	Yes
91	04/01/13 22:19	06/03/13 13:41	62.6	No
50	04/01/13 23:13	08/11/13 22:47	132.0	No
86	04/02/13 22:47	04/26/13 21:26	23.9	Yes
69	04/02/13 23:48	04/03/13 04:14	0.2	Yes
70[a]	04/03/13 04:40	04/03/13 22:01	0.7	Yes
92	05/07/13 02:23	06/11/13 03:31	35.0	No
71	05/08/13 21:16	06/06/13 16:30	28.8	No

[a] Fish passed Wapato, fellback over the dam, and passed a second time. Only the first passage is included here.

Table 7. Below dam residence summary for radio-tagged Pacific lampreys at released downstream of Wapato Dam from August 2012 - August 2013.

Release	Passage success	*n*	Duration (days)	Mean (days)	Median (days)	SD (days)
Fall	Yes	12	0.08 - 3.02	0.73	0.16	1.04
	No	0	--	--	--	--
Spring	Yes	7	0.18 – 23.94	4.67	0.95	8.57
	No	6	28.80 – 154.85	78.38	59.80	52.47

Dam passage efficiency and Fishway passage - Of the 55 Pacific lampreys that approached Wapato Dam (including fish that were released below Sunnyside and above Wapato dams), 45 passed upstream resulting in an overall dam passage efficiency of 82% (Table 8, Table 9, Table 10). Passage efficiency for the fall-release fish was 95%, as 37 lampreys approached the dam, and 35 passed. The first seventeen fall-release lampreys passed within 2 days of release; the next 17 fish passed within 14 days of release, and one fish overwintered below the dam and passed on May 8, 2013, 254 days after release.

As with Sunnyside Dam, Wapato passage efficiency was reduced for the spring-release group. Of the 18 spring-release lampreys that approached the dam, 10 passed successfully, resulting in a spring passage efficiency of 55%. One fish (code 70) passed two times. Spring-release group passage events took place in April (n = 8), May (n = 2), and June (n = 1) of 2013.

Of the lampreys passing Wapato Dam, 27 were released below Sunnyside Dam, while 18 were released below Wapato Dam (Table 8, Table 9, and Table 10). Lampreys used the left (41%), center (22%), and right (20%) fishways, and the dam face (17%) to pass Wapato Dam (Table 8, Table 9, and Table 10).

The duration of Wapato Dam passage events ranged from 0.1 – 23.5 hours. (Table 8). All but one passage event lasted less than four hours, and 50% lasted less than one hour. The lone 23.5 hour passage event occurred overnight. Mean passage times were longer in the spring (3.3 hours) than fall (1.0 hours). Passage times also varied with location, mean passage time at the river right ladder (3.5 hours) took longer than at the left (1.26 hours) or center (0.55 hours) ladders. Passage times were not calculated for fish passing via unknown routes.

Table 8. Wapato Dam fishway data: dates of entry and exit, total time in the fish ladder, and mean daily water temperature at passage for radio-tagged adult Pacific lampreys released downstream of Wapato Dam, August 2012 through August 2013.

Code	Release Site/Period	Fishway	Entered Ladder	Exited Ladder	Time in Ladder (hr)	Temp °C
29	BWD/Fall	L. Ladder	08/27/12 23:48	08/28/12 00:17	0.49	17.9
46	BWD/Fall	L. Ladder	08/28/12 00:50	08/28/12 02:30	1.67	18.1
39	BWD/Fall	L. Ladder	08/28/12 01:59	08/28/12 05:15	3.26	18.1
6	BWD/Fall	C. Ladder	08/28/12 02:22	08/28/12 02:30	0.14	18.1
43	BWD/Fall	L. Ladder	08/28/12 04:45	08/28/12 05:21	0.60	18.1
30	BWD/Fall	C. Ladder	08/29/12 00:18	08/29/12 00:41	0.39	17.4
44	BWD/Fall	L. Ladder	08/29/12 00:24	08/29/12 01:22	0.96	17.4
24	BWD/Fall	R. Ladder	08/31/12 01:26	08/31/12 02:12	0.77	17.7
37	BWD/Fall	L. Ladder	09/01/12 01:57	09/01/12 03:20	1.39	16.8
22	BWD/Fall	C. Ladder	09/10/12 00:51	09/10/12 01:01	0.17	16.4
77	BWD/Spring	R. Ladder	03/31/13 22:54	04/01/13 22:23	23.49	--

Table 8 Continued

Code	Release Site/Period	Fishway	Entered Ladder	Exited Ladder	Time in Ladder (hr)	Temp °C
88	BWD/Spring	C. Ladder	04/01/13 21:21	04/01/13 22:24	1.06	--
61	BWD/Spring	R. Ladder	04/02/13 22:01	04/02/13 23:32	1.51	--
69	BWD/Spring	C. Ladder	04/03/13 04:14	04/03/13 05:49	1.59	--
70[a]	BWD/Spring	L. Ladder	04/03/13 22:01	04/03/13 22:47	0.76	--
70[a]	BWD/Spring	C. Ladder	04/04/13 00:47	04/04/13 01:38	0.85	--
86	BWD/Spring	C. Ladder	04/26/13 21:26	04/26/13 21:49	0.39	11.9

[a] Fish passed the dam twice, both passage times reported here.

Table 9. Wapato Dam fishway data: dates of entry and exit, total time in the fish ladder, and mean daily water temperature at passage for radio-tagged adult Pacific lampreys released downstream of Sunnyside Dam, August 2012 through August 2013.

Code	Release Site/Period	Fishway	Entered Ladder	Exited Ladder	Time in Ladder (hr)	Temp °C
38	BSD/Fall	L. Ladder	08/28/12 02:07	08/28/12 02:57	0.85	18.1
8	BSD/Fall	R. Ladder	08/28/12 02:29	08/28/12 03:10	0.68	18.1
41	BSD/Fall	L. Ladder	08/28/12 03:01	08/28/12 03:07	0.10	18.1
12	BSD/Fall	R. Ladder	08/28/12 03:17	08/28/12 03:51	0.57	18.1
21	BSD/Fall	L. Ladder	08/28/12 03:51	08/28/12 04:48	0.94	18.1
14	BSD/Fall	L. Ladder	08/28/12 05:07	08/28/12 06:00	0.88	18.1
35	BSD/Fall	L. Ladder	08/28/12 21:46	08/28/12 22:23	0.62	18.1
25	BSD/Fall	L. Ladder	08/29/12 00:35	08/29/12 01:15	0.67	17.4
20	BSD/Fall	C. Ladder	08/29/12 01:03	08/29/12 01:25	0.37	17.4
23	BSD/Fall	L. Ladder	08/31/12 04:56	08/31/12 06:53	1.95	17.7
45	BSD/Fall	L. Ladder	09/01/12 02:17	09/01/12 05:56	3.66	16.8
4	BSD/Fall	R. Ladder	09/02/12 00:57	09/02/12 01:21	0.40	16.8
31	BSD/Fall	C. Ladder	09/03/12 00:42	09/03/12 00:52	0.16	16.9
9	BSD/Fall	L. Ladder	09/03/12 01:22	09/03/12 02:53	1.52	16.9
47	BSD/Fall	L. Ladder	09/03/12 03:09	09/03/12 04:40	1.53	16.9
32	BSD/Fall	L. Ladder	09/05/12 22:59	09/06/12 00:44	1.75	17.1
36	BSD/Fall	L. Ladder	09/06/12 23:20	09/07/12 00:08	0.79	17.2
33	BSD/Fall	C. Ladder	09/07/12 23:44	09/07/12 23:50	0.10	16.8
75	BSD/Spring	R. Ladder	04/18/13 20:18	04/18/13 23:15	2.95	8.8
93	BSD/Spring	R. Ladder	05/08/13 00:25	05/08/13 00:37	0.20	12.3
85	BSD/Spring	R. Ladder	06/05/13 02:01	06/05/13 02:40	0.66	15.0

Dam face passage- Eight tagged lampreys were not detected entering a fishway and instead passed Wapato Dam by climbing the face of the dam (Table 10). Seven of these lampreys were fall releases, including five from below Sunnyside Dam where they had passed in the ladders. Five lampreys climbed Wapato Dam in the west channel, including four that used the right face between the fishway and the right bank and one that climbed the left face between the fishway and the island. Three lampreys climbed Wapato Dam in the east channel and all used the right face between the fishways. Based on interpretation of antenna detections and signal strength, most lampreys passed on their first attempt and took only 1-4 h to climb (Table 10). Code 15, which had overwintered at the dam, was not successful until its fifth attempt in the spring, when it took 11 h to climb and finally pass. Tagged lamprey that passed on the dam face did so on similar dates and under similar temperature and flow conditions as those using the ladder.

Table 10. Wapato Dam face passage data: route selection, timing, and duration of passage for radio-tagged adult Pacific lampreys, August 2012 through August 2013.

Code	Release Location/Period	River Channel	Dam Face	Start Climb	Finish Climb	Climb Time (hr:mm)
7	BWD/Fall	East	Right	08/27/12 23:00	08/28/12 03:23	4:23
42	BSD/Fall	East	Right	09/03/12 20:11	09/03/12 23:23	3:12
40	BSD/Fall	West	Right	09/04/12 21:49	09/04/12 23:03	1:14
13	BSD/Fall	East	Right	09/05/12 20:30	09/05/12 21:34	1:04
16	BSD/Fall	West	Right	09/05/12 21:00	09/05/12 23:12	2:12
10	BWD/Fall	West	Right	09/09/12 19:00	09/09/12 22:53	3:53
15	BSD/Fall	West	Left	05/08/13 02:06	05/08/13 13:08	11:02
52	BSD/Spring	West	Right	05/09/13 21:31	05/10/13 01:07	3:36

Wapato Diversion Canal residence- One tagged lamprey was entrained in the Wapato Canal. Code 15 was released downstream of Sunnyside Dam on August 27, 2012. It passed that dam, arrived at Wapato Dam on October 16, 2012 and was located in the west channel downstream of the right bank fishway on October 18, 2012. It was recorded downstream of the dam through the winter and spring until May 8, 2013, when it was detected on the left aerial antenna climbing the left face of the dam between the fishway and the island. Antenna detections indicate code 15 moved across the river above the dam and became entrained in the Wapato Canal. It resided just downstream of the trash rack for 53 days, from May 8 until June 30, 2013, when it exited the canal as indicated by the last detection on the upstream aerial antenna. On July 5, 2013, code 15 was detected in the Roza Canal Wasteway Outfall at the powerhouse pool.

Discharge- Pacific lampreys passed Wapato Dam at a variety of discharge levels (Figure 15). Those passing in the fall did so at relatively low flows between 600 and 965 ft^3/s. Those passing during the spring months did so at widely varying flows between 2,500 and 8,100ft^3/s. The majority of passage events, especially in the spring, occurred during periods of increasing discharge.

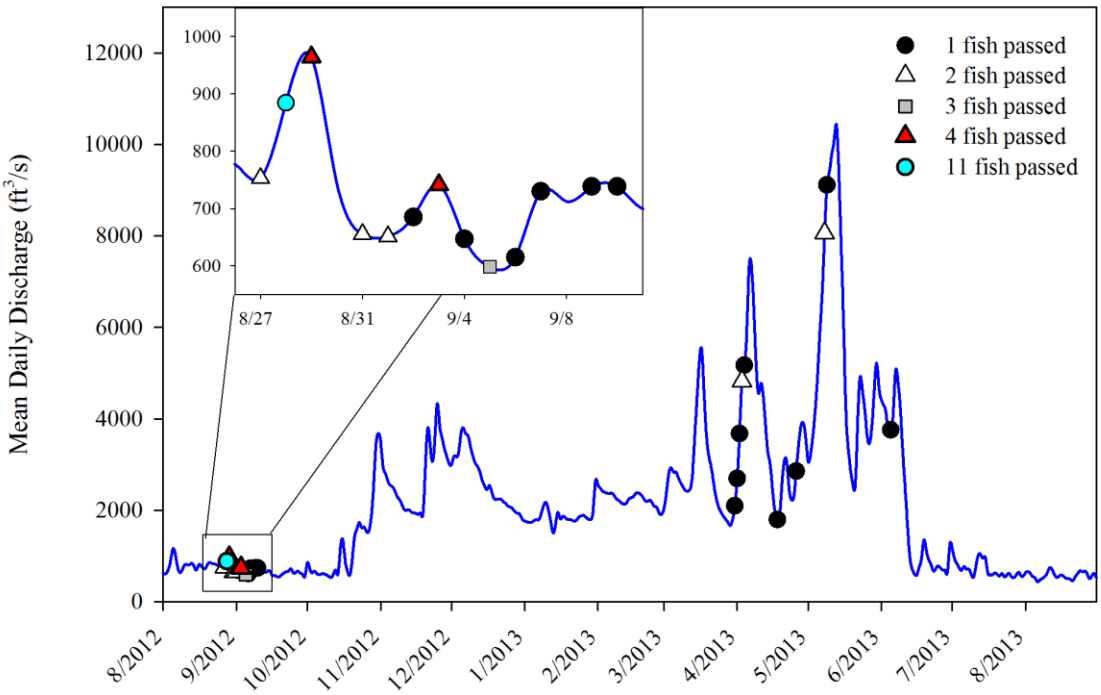

Figure 15. Mean daily discharge and passage timing of radio-tagged lampreys at Wapato Dam on the Yakima River, August 2012 through August 2013.

Temperature- Water temperatures of the Yakima River were recorded at Wapato Dam between August 1, 2012 and January 20, 2013, and between April 8, 2013 and August 31, 2013 (Figure 16). In late March and early April 2013, six tagged lampreys passed Wapato Dam, and temperature data from Sunnyside dam has been substituted to understand their movements with relation to water temperature.

Throughout Phase 2, mean daily water temperatures varied from 3.1 to 20.5 °C. Lamprey passage occurred during mean daily water temperatures of 8.7 to 18.1 °C, with fall passage events occurring at warmer temperatures than spring passage events (Figure 16). In the fall, water temperatures rapidly declined to less than 16 °C after the last lamprey passed the dam and movements below the dam generally ceased for the remainder of the fall.

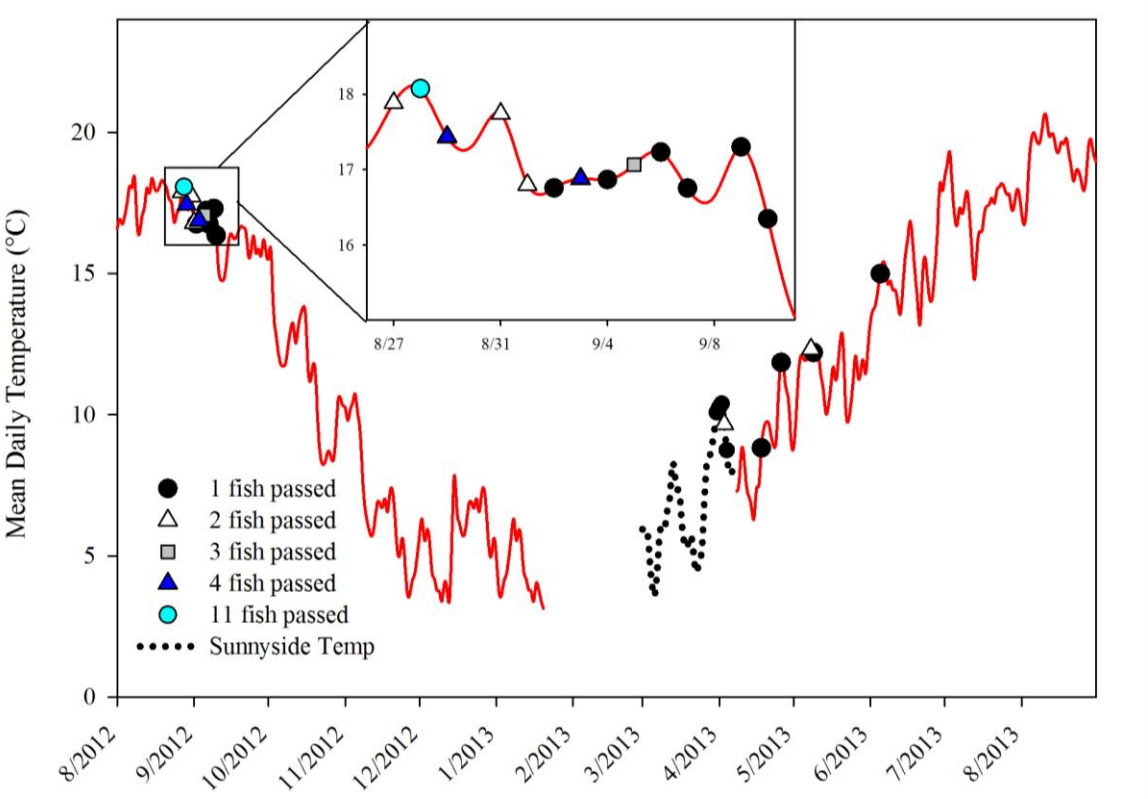

Figure 16. Mean daily water temperatures and passage timing of radio-tagged lampreys at Wapato Dam on the Yakima River, August 2012 through August 2013. Wapato Temperature data from January 20 – April 8, 2013 are not available; Sunnyside Dam temperature data were substituted from March 1 – April 7, 2013.

Above dam residence- For lampreys that passed using fishways, the time spent above Wapato Dam ranged from 2.8 minutes to 5.8 days. Most fished moved quickly upstream and 26 of 35 lampreys resided for less than one hour before moving out of detection range. Two exceptions were observed. Code 70 passed the dam on April 3, 2013, fell back over it, and passed the dam a second time on the following day. As described above, code 15 entered the Wapato Diversion Canal, where it resided for 53 days before moving upstream.

Roza Wasteway #2

A substantial number of tagged lampreys entered and used the Roza Wasteway #2 (see Figure 17). During the fall migration, 20 of the 49 tagged lampreys that passed Wapato Dam (or that were released above and remained above the dam) entered the Wasteway through the salmon exclusion screening (Table 11). During the spring release, 4 of the 11 tagged lampreys that passed Wapato Dam entered the Wasteway. Most entered within 2 weeks of passing Wapato Dam although two fall-release fish waited until spring (tag 42) or summer (tag 15). Four lampreys (tags 4, 23, 30, 44) moved between the Wastway outfall and the river several times. Minimum known residence in the Roza Wasteway #2

ranged from 1.4 to 324 days; three lampreys spent less than 7 days and seven lampreys spent more than 300 days in the Wasteway (Table 11).

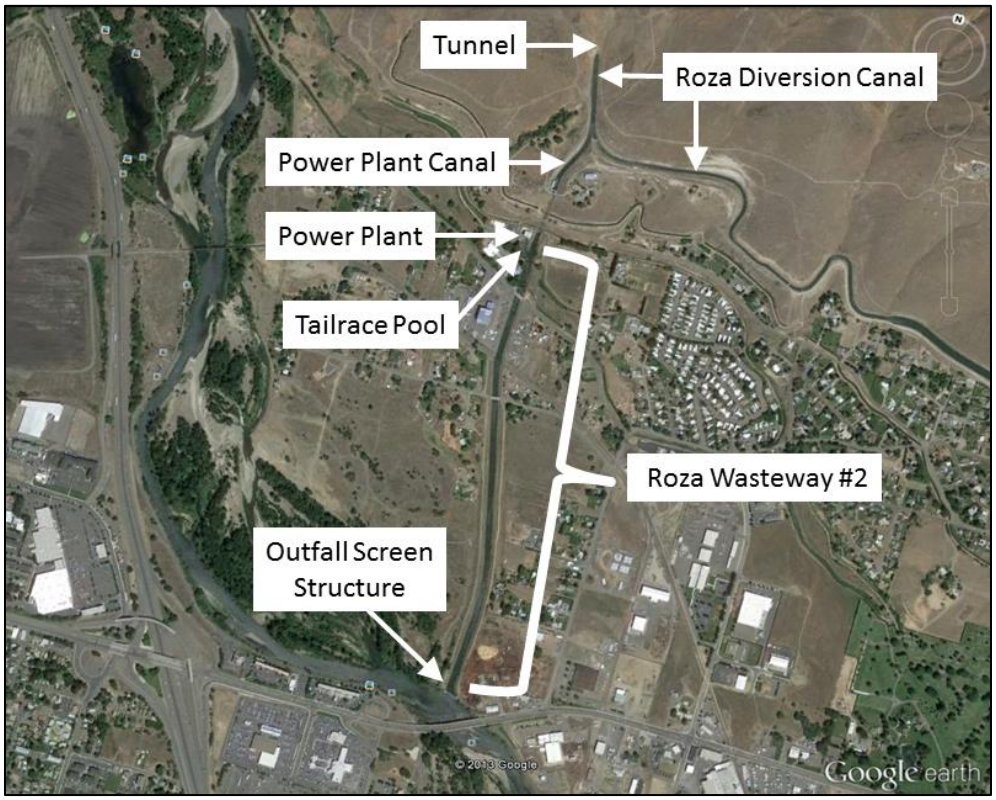

Figure 17. Aerial photograph showing the Roza Diversion Canal emerging from the tunnel, the Roza Power Plant Canal diverging from the main canal, and the locations of the Roza Power Plant, Tailrace Pool, Roza Wasteway #2, and Wasteway Outfall.

Table 11. Roza Wasteway #2 entry and residence data for radio-tagged adult Pacific lampreys, August 2012 through August 2013.

Tag ID	Release Site	Release Date	1st Date Roza Outfall	Last Date Roza Outfall	Total Time at Outfall (days)	Minimum Residence (days)	Exit?	1st Date Upstream Dam
4	BSD	08/27/12	09/12/12	05/09/13	238.8	26.0	yes	--
7	BWD	08/27/12	09/12/12	07/26/13	316.5	317.0	no	--
8	BSD	08/27/12	04/25/13	05/28/13	33.5	33.5	yes	--
9	BSD	08/27/12	09/03/12	12/20/12	107.1	106.0	yes	--
11	AWD	08/27/12	09/12/12	07/26/13	317.0	317.0	no	--
15	BSD	08/27/12	07/05/13	08/19/13	45.1	44.6	unk	--
17	AWD	08/27/12	09/05/12	07/05/13	303.0	303.0	no	--
20	BSD	08/27/12	09/18/12	05/24/13	248.7	248.2	yes	--
23	BSD	08/27/12	09/05/12	10/28/12	53.1	12.8	yes	09/15/12[a]

Table 11 Continued

Tag ID	Release Site	Release Date	1st Date Roza Outfall	Last Date Roza Outfall	Total Time at Outfall (days)	Minimum Residence (days)	Exit?	1st Date Upstream Dam
24	BWD	08/27/12	09/12/12	09/14/12	2.1	1.6	yes	--
25	BSD	08/27/12	09/12/12	07/11/13	302.0	302.0	no	--
30	BWD	08/27/12	09/05/12	07/26/13	324.0	188.0	no	--
31	BSD	08/27/12	09/12/12	09/12/12	7	7	yes	02/27/13[b]
38	BSD	08/27/12	09/18/12	05/28/13	252.9	252.9	yes	--
39	BWD	08/27/12	09/05/12	09/15/12	11.0	10.5	yes	05/20/13[a]
42	BSD	08/27/12	04/25/13	05/05/13	10.1	9.6	yes	--
43	BWD	08/27/12	09/12/12	09/13/12	1.9	1.4	yes	09/16/12[a]
44	BWD	08/27/12	09/28/12	05/20/13	234.2	34.3	yes	--
45	BSD	08/27/12	09/05/12	07/26/13	324.0	324.0	no	--
46	BWD	08/27/12	09/05/12	07/26/13	324.0	324.0	no	--
61	BWD	03/20/13	04/08/13	05/31/13	53.0	52.5	yes	--
75	BSD	03/20/13	04/25/13	06/19/13	55.0	36.5	unk	--
85	BSD	03/20/13	06/19/13	07/26/13	37.0	33.5	unk	--
88	BWD	03/20/13	04/17/13	04/17/13	--	unk	unk	--

[a] Cowiche Dam
[b] Roza Dam

During mobile tracking the majority of lampreys were detected in the power plant tailrace pool (Figure 17 and Figure 18) and a few were distributed downstream in the Wasteway to the outfall screens (Figure 17). The number of lampreys recorded at the power plant tailrace pool in the spring of 2013 ranged from five tags on April 1, to 11 tags on April 25 and May 9. Thirteen of the tagged lamprey eventually exited the Wasteway; seven were last detected within the Watseway, and exit status of four is unknown. A total of nine lampreys were present during the presumed spawning period (mid-June to late July, 2013), including two that first entered the Wasteway at that time. Several lampreys moved downstream after exiting and only four lampreys were subsequently detected at upstream stations- three at Cowiche Dam and one at Roza Dam (Table 11).

Several features may influence lamprey behavior at the site. The Yakima River thalweg is on the same side of the river as the Wasteway due to the gravel bar that spans most of the river channel (Figure 19). At lower flows this gravel bar also appears to guide lampreys directly to the Roza Wasteway #2 Outfall (Figure 20). The spacing of bars in the screen structure is designed to exclude adult salmon but adult lampreys are not deterred (Figure 21). The Roza Canal was dewatered and the Wasteway shut off from late October to late November during 2012, but water still flowed from subsurface sources in the outfall canal and the lampreys apparently survived until diversion water flowed again on November 24.

Figure 18. The Roza Power Plant showing the tailrace pool where 7 tagged adult Pacific lampreys were present when Roza Wateway #2 was shut off for annual maintenance during November, 2012.

Figure 19. Aerial photo showing the gravel bar and thalweg of the Yakima River at the Roza Wasteway #2 confluence.

Figure 20. The Yakima River thalweg and gravel bar located downstream of the Roza Wasteway #2 outfall screen structure.

Figure 21. The Roza Wasteway #2 outfall screen structure at the Yakima River confluence, with the gravel bar visible beyond screen.

Roza Dam

Fishway passage-Twelve study lampreys approached Roza Dam between September 1, 2012 and May 9, 2013. Eleven of these were detected at fishway entrances, and eight were detected at interior fishway antennas (Table 12). Most of the lampreys (11 of 12) that reached Roza Dam were released in the fall. Eight of 11 fall release fish approached in the fall within 12 days of release, and four approached in the spring after overwintering downstream. Lampreys that approached Roza were released below both Wapato (n = 4) and Sunnyside (n = 8) dams.

Table 12. Roza Dam approach and passage summary for radio-tagged adult Pacific lampreys, August 2012 through August 2013.

Fish ID	Release Site/Time	First Roza Detection	Roza Highpoint	Pass?
29	BWD/Fall	08/28/12 11:29	Fish facility holding pen	No
41	BSD/Fall	08/31/12 23:35	Downstream of dam	No
6	BWD/Fall	09/01/12 00:08	Right fishway entrance	No
35	BSD/Fall	09/02/12 23:43	Fish facility holding pen	No
12	BSD/Fall	09/03/12 22:42	Fish facility holding pen	No
21	BSD/Fall	09/06/12 01:01	Fish facility holding pen	No
14	BSD/Fall	09/06/12 02:11	Fish facility holding pen	No
40	BSD/Fall	09/08/12 02:45	Fish facility holding pen	Yes[a]
32	BSD/Fall	03/14/13 19:58	Right and left fishway entrances	No
22	BWD/Fall	04/03/13 00:28	Right fishway interior	No
86	BWD/Spring	05/09/13 00:35	High water ladder exit	No
47	BSD/Fall	05/11/13 17:10	Right and left fishway entrances	No

[a] One untagged lamprey was released from the holding pen intro the forebay, and we assume this was the study fish that shed tag code 40 which was later recovered in the fish facility.

Salmon facility holding pen- Of the 12 tagged lampreys that approached Roza Dam, six ascended the fish ladder and were detected in the salmon trapping facility (Table 12). All were from the fall release group, with five release downstream of Sunnyside Dam and one released downstream of Wapato Dam. During mobile tracking on September 8, 2012, four lampreys were detected in the holding pen. Because Roza Dam was initially wired as a simple gate station with only one downstream antenna, additional antennas were then set up to monitor the fish ladder and fish processing facility.

Based on the mobile and antenna detections, the lampreys ascended the ladder and entered the holding pen within 1 to 6 days after first approaching the dam. Three lampreys (codes 12, 14, 21) spent 1 day, one (code 35) spent 12.5 days, and one (code 29) spent 26.5 days in the facility. Code 40 was detected in the pen for 40 days, but when the tank was emptied on October 24, 2012, the transmitter was recovered. An untagged lamprey was passed upstream by the trapping crew during the previous week and was assumed to be code 40.

Cowiche Dam

Dam passage efficiency and Fishway passage - Ten lampreys approached Cowiche dam, between September 5, 2012 and June 6, 2013 (Table 13). Of these, six passed resulting in a dam passage efficiency of 60%. Passage routes at Cowiche were mostly unknown, as fishway monitoring antennas were installed on February 26, 2013 after the fall release lampreys had passed. The one lamprey (code 52) passed in the spring used the left fishway.

Table 13. Cowiche Dam approach and passage data for radio-tagged adult Pacific lampreys, August 2012 through August 2013.

Fish ID	Release Site/Time	First Cowiche Detection	Pass?	Ladder	Passage Date
28	AWD/Fall	09/05/12 21:30	Yes	Unknown	09/05/12
37	BWD/Fall	09/08/12 04:03	Yes	Unknown	09/08/12
16	BSD/Fall	09/09/12 02:38	Yes	Unknown	09/09/12
33	BSD/Fall	09/11/12 01:53	Yes	Unknown	09/13/12
24	BWD/Fall	09/15/12 19:22	Yes	Unknown	09/15/12
43	BWD/Fall	09/16/12 06:58	No	--	--
10	BWD/Fall	09/21/12 03:48	No	--	--
39	BWD/Fall	05/20/13 02:43	No	--	--
52	BSD/Spring	06/08/13 07:52	Yes	L. Ladder	06/10/13
47	BSD/Fall	09/12/13 18:47	No	--	--

Five of the six lampreys that passed remained above Cowiche Dam and continued migrating up the Naches River. Code 28 passed the dam and initially moved up the Naches River before reversing course and moving downstream back over Cowiche Dam and out to the confluence with the Yakima River. Two lampreys (codes 10 and 43) overwintered below the dam.

Last Known and Uppermost Detections

Last Known Detections

It is unclear if the last known detections represent the final locations of study lampreys. These detections may represent several scenarios including:

1) Tag retained: Indicates location of lamprey carcasses (mortality or predation)
2) Tag retained: Indicates location where transmitter battery failed, and lamprey movements continued but were not detected.
3) Tag shed: Indicates location where transmitter was expelled, and lamprey movements continued but were not detected.

Determining the last known detection type was beyond the scope of this study. One tag, with code 40 was recovered from the Roza Dam fish facility, and a single untagged

lamprey (assumed to have shed this tag) was released into the dam forebay, but the circumstances around the remaining last detections are unknown.

The last known detection locations of radio-tagged lampreys through August 1, 2013 are summarized in Table 14. Seventy study lampreys were last detected in the Yakima River drainage, whereas 10 were last located in the Naches River system. Most codes remained in the mainstem Yakima River below Sunnyside and Wapato dams, or in the reach below Roza Dam. However, several lampreys were last detected in off-channel locations including the Roza Wasteway Canal (n = 11) and the Sunnyside Diversion Canal (n = 1), suggesting these structures may pose an entrainment risk for migratory adult lamprey (Table 14). Last detections of tagged lampreys in the Naches River system were located both upstream (n = 5) and downstream (n = 5) of Cowiche Dam (Table 14).

Table 14. Summary of last known detection locations (dam or reach) of radio-tagged Pacific lampreys released in Yakima River during fall 2011 and spring 2012.

Reach	Number final detections
Below Sunnyside Dam	20
Sunnyside Diversion Canal	1
Between Sunnyside and Wapato dams	17
Between Wapato Dam and Roza Outfall	8
In the Roza Wasteway Canal	11
Between Roza Outfall and Roza Dam	12
Above Roza Dam	1
Between the Naches confluence and Cowiche Dam	5
Above Cowiche Dam	5

Uppermost Detections: Naches River

The six radio-tagged lampreys that passed Cowiche Dam were detected from the Cowiche Dam headpond (rkm 6.5) to the town of Cliffdell (rkm 53). The uppermost detection locations of these lampreys are shown in Figure 22. Three lampreys passed an additional diversion dam, Wapatox Dam (rkm 28). Four of the six lampreys that passed Cowiche Dam were ultimately documented moving back downstream before being detected for the final time.

Naches River habitat above Cowiche Dam includes extensive networks of gravel bar and cobble islands, side channels, oxbows and backwaters. Apart from the Tieton River (rkm 29), most of the Naches River tributaries are steep, cold water streams. It is not clear how radio-tagged lampreys were using Naches River and its tributaries, but high quality spawning and rearing habitats are available in the mainstem river, and possibly in the side tributaries as well.

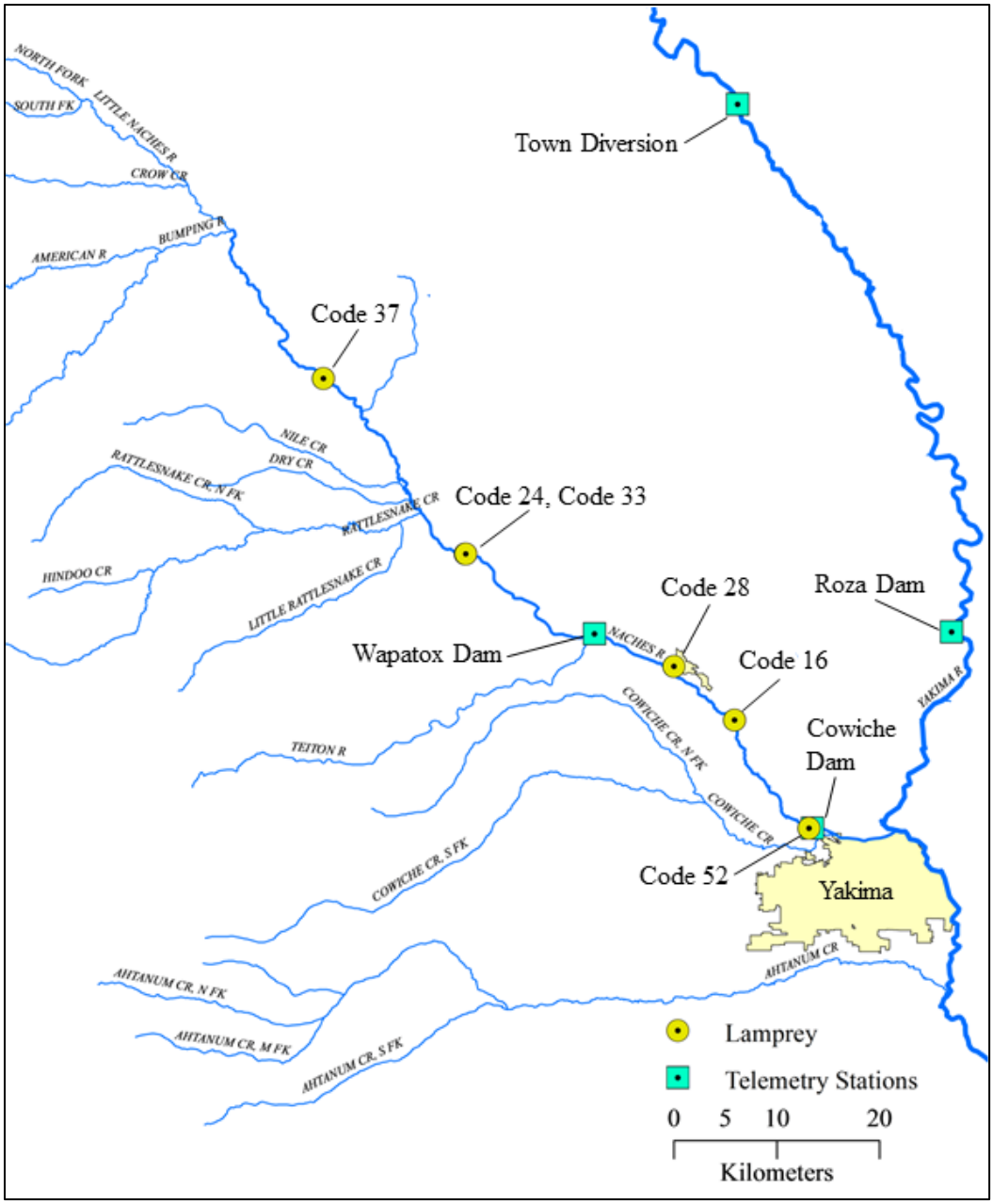

Figure 22. Last known locations of radio-tagged Pacific lampreys in the Naches River from August 2012 to August 2013.

Multiple Dam Passage

With the exception of Wapato Dam in the fall, the numbers of radio-tagged lampreys passing multiple dams was small (Table 15). Of the 47 lampreys released downstream of Sunnyside Dam, only three (6%) passed three successive diversion dams (including Cowiche Dam); two lampreys from the fall and one from the spring release group. Although one lamprey passed Roza Dam, this fish was removed from the holding pen by the fish facility staff, and therefore has been excluded from passage calculations.

Lampreys having passed at least one dam had overall passage success rates (# pass / # approach) of 90% at Wapato Dam, 56% at Cowiche Dam, and 0% at Roza Dam. Passage success at multiple dams was highest for lampreys passing Wapato Dam in the fall. Lampreys released below Sunnyside dam that approached Wapato Dam in the fall passed with 100% success. Multiple dam passage success at Wapato Dam was less spring, decreasing to 57%. This reduction in springtime dam passage efficiency at Wapato Dam was also observed for lamprey released below Wapato Dam but above Sunnyside Dam (100% in fall to 50% in spring) suggesting that passage conditions were better in the fall for both groups).

Table 15. Release site, period, and number of radio-tagged Pacific lampreys that passed the lower four diversion dams on the Yakima River during fall 2011 and spring 2012.

		Number of Passage Events							
Release Site And Period	**n**	**SUN Fall**	**SUN Spring**	**WAP Fall**	**WAP Spring**	**ROZ Fall**	**ROZ Spring**	**COW Fall**	**COW Spring**
BSD/Fall	25	24		22	1	1[a]		2	
BSD/Spring	22		7		4				1
BWD/Fall	15			12				2	
BWD/Spring	13				6[b]				
AWD/Fall	5		1					1	
Totals	***80***	***24***	***8***	***34***	***11***	***1***		***5***	***1***

[a] One untagged lamprey was released from the holding pen intro the forebay, and we assume this was the study fish that shed tag code 40 which was later recovered in the fish facility.
[b] Code 70 passed Wapato twice, but only one passage event is included here.

Discussion

Phase 2 of our telemetry study was completed during the 2012 migration season. A total of 80 adult Pacific lampreys were radio-tagged and released at Sunnyside and Wapato dams. Nearly all the tagged lampreys moved upstream and actively attempted to pass the diversions.

Passage Efficiencies

Overall passage efficiencies at Wapato Dam (82%) and Sunnyside Dam (68%) were higher than the overall passage efficiencies recorded during Phase 1 at Wanawish Dam (62%) and Prosser Dam (48%) (Johnsen et al. 2013). Seasonal dam passage efficiencies were inverted during Phase 2, relative to Phase 1. Dam passage efficiencies for fall-release fish were substantially higher than spring-release fish at Sunnyside (96% fall, 33% spring) and Wapato (95% fall, 55% spring), but not at Wanawish (53% fall, 71%

spring) or Prosser (50% fall, 45% spring). These local and seasonal differences present additional challenges to upstream migrations: in the fall, fewer lampreys are able to pass the lower dams to take advantage of the seasonal high passage efficiencies at the upstream dams; conversely, in the spring more lampreys are able to pass the lower dams but they are then confronted with low passage efficiencies at the dams upstream.

The dam passage efficiency at Wapato Dam was supplemented by tagged lampreys passing up and over the face of the dam. This "climbing" ability outside of the ladders increased overall dam passage efficiency from 67% to 82%. We were unable to pinpoint the exact locations where climbing occurred, but apparently some combination of conditions at the dam is conducive to the behavior. It may be that logs or debris hang up on the dam and create hydraulic actions that favor the climbing ability. Characteristics of the dam face such as smoothness of the concrete and flow pattern at the ladder intersections may also be a factor. Modifications such as flow deflectors on the fishway walls upstream of the dam may create calmer flow conditions for a climbing route at the face (Figures 23 and 24). Metal plating curved to fit the face of the dam below the deflector may provide a better surface for oral disk attachment to increase climbing success of the lamprey. Close inspection of the dam faces at varying flows would be instructive for designing this type of passage assistance.

Figure 23. Photograph of the right bank of Cowiche Dam showing a log hung up on crest that deflects flow and calms turbulence at the intersection of the dam face and fishway wall, resulting in conditions that may favor lamprey climbing behavior to pass a dam.

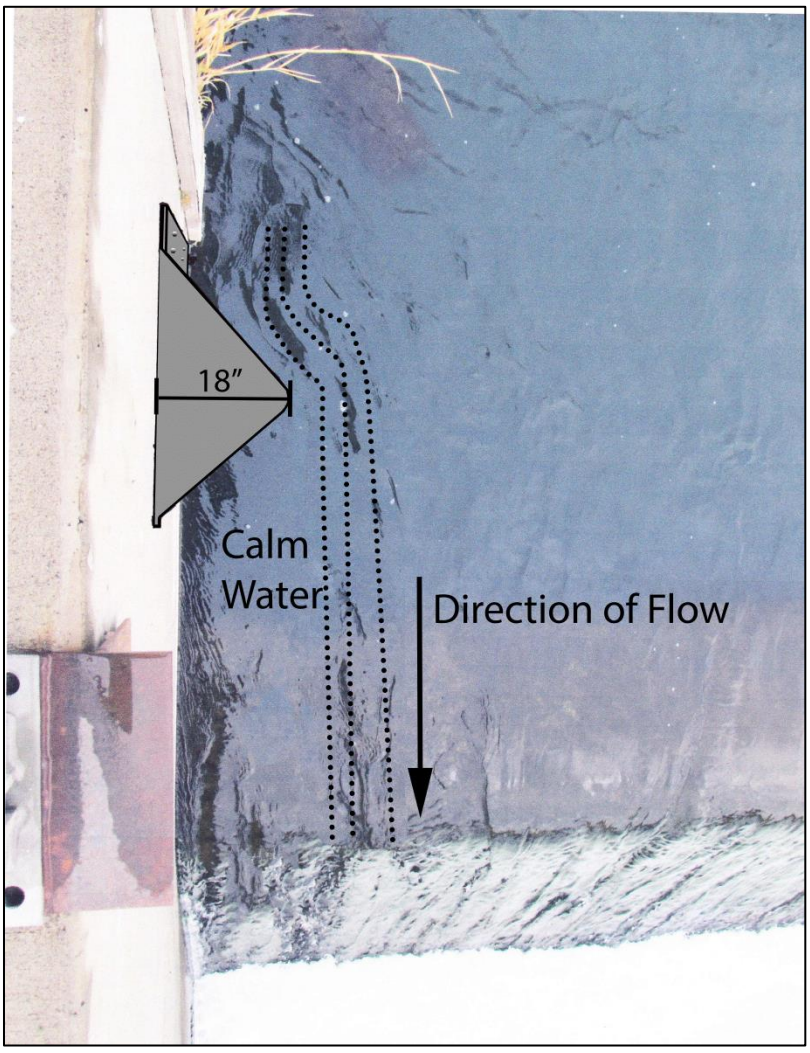

Figure 24. Photograph with concept drawing of deflector designed to create flows conducive to climbing adult lamprey at Sunnyside Dam (design created by J. Simonson of Fish Head Technology and Mark Nelson USFWS).

Entrainment in Canals

The majority of the tagged fish quickly moved upstream after passing a dam but some entrainment occurred in canals during the 2012 migration. One tagged lamprey resided in the Sunnyside Canal just upstream of the screening for 2 months before moving upstream. Another lamprey resided in the canal for a year before the battery died, but because this lamprey moved downstream from the release location upstream of Wapato Dam, the entrainment and residence is most likely a tagging effect. One lamprey resided in the Wapato Canal near the trash rack for two months before moving upstream. Only one entrainment was documented during Phase 1 at Wanawish Dam in the 2011 migratory season. Overall, entrainment in canals after passing a diversion has occurred at a relatively low frequency during our study to date.

Roza Wasteway #2

A significant number of tagged lampreys (24 of 60) entered and resided in the outfall of the Roza Wasteway #2, including 11 that overwintered at the powerhouse pool. Lampreys that overwintered in the canal for about 250 days survived and exited in May, 2013, but those that spent over 300 days were not detected leaving before the transmitter batteries died. Thus several tagged fish survived in the powerhouse pool during the November 2012 shutdown of Roza Canal, but the overall survival rate is unknown. It appears some of the lampreys may have attempted to spawn in the Wasteway while others re-entered the Yakima River and continued upstream migration to potential spawning areas.

Several factors could influence lamprey use of the Wasteway. It may be that the hydrology and morphology of the river channel and outfall simply guide lampreys into the canal and they perceive it as a natural tributary. The gravel bar at the confluence and the gravel in the canal outfall may be attractive spawning substrate. The powerhouse pool appears to provide overwinter habitat of cobble and rubble. The Wasteway water originates from Roza Dam and may be more temperate than the mainstem Yakima River during late summer, and subsurface flows may also moderate temperatures that are seasonally attractive to the lamprey.

To further evaluate lamprey entrainment and or use of Roza Wasteway #2, pot traps should be placed in the powerhouse pool to monitor use by untagged lampreys. If it is decided that the effect of the Wasteway on lamprey behavior and movement is negative, then consideration should be given to upgrading the salmon screening to exclude adult lamprey from the outfall. Alternatively, the Wasteway and vicinity could used as a migratory lamprey collection location. Traps could be constructed to capture run of the river adult lampreys for future research and potentially supplementation efforts.

Roza Dam Salmon Facility

Few if any lampreys have been reported at Roza Dam, whether in the fishway or the salmon trapping facility. Code 40 was apparently the first lamprey ever observed passing through the facility since it was constructed in 1995 (Mark Johnston, YN Fisheries, pers. comm.). About 50% of the tagged lamprey that migrated to Roza Dam during Phase 2 ascended the fish ladder and entered the facility, comparable to efficiencies at the lower Yakima River fishways. As constructed and operated, however, the fish facility is essentially a dead end for lamprey migration. The fish crowder in the trap is ineffective in moving lampreys into the fish elevator because of a gap at the bottom of the screen due to the slanted floor of the tank: lampreys simply swam under and resided behind the crowder. Observations by the trapping crew on the location and behavior of tagged lampreys in the tank resulted in a simple solution that may allow lampreys to continue upstream migration. In November 2013, during the maintenance drawdown of the forebay, the USBOR drilled a 3 inch diameter hole through the cement wall of the tank behind the crowder, providing an “escape hatch” for lamprey to swim out into the dam forebay and continue upstream migration (Mark Johnston, YN Fisheries, pers. comm.). The effectiveness of this modification will be monitored during the Phase 3 releases at Roza Dam.

Lamprey Passage Structure

Dams with low passage rates and localized lamprey holding areas are prime candidates for lamprey passage structures (LPS) (Moser et al. 2006, Moser et al. 2011). Specific locations of congregating lampreys were not found at Sunnyside or Wapato dams, so there are no obvious places to site a LPS. At Sunnyside Dam, however, the majority of the lampreys searched around the center island before entering and passing in that ladder, indicating that the downstream end of the island may be a suitable location for a LPS. The structure could be designed as a simple ramp with a rest box that returns the lamprey to the fish ladder (Figure 25) or as a larger system that returns the lamprey to the river upstream of the dam (Figure 26).

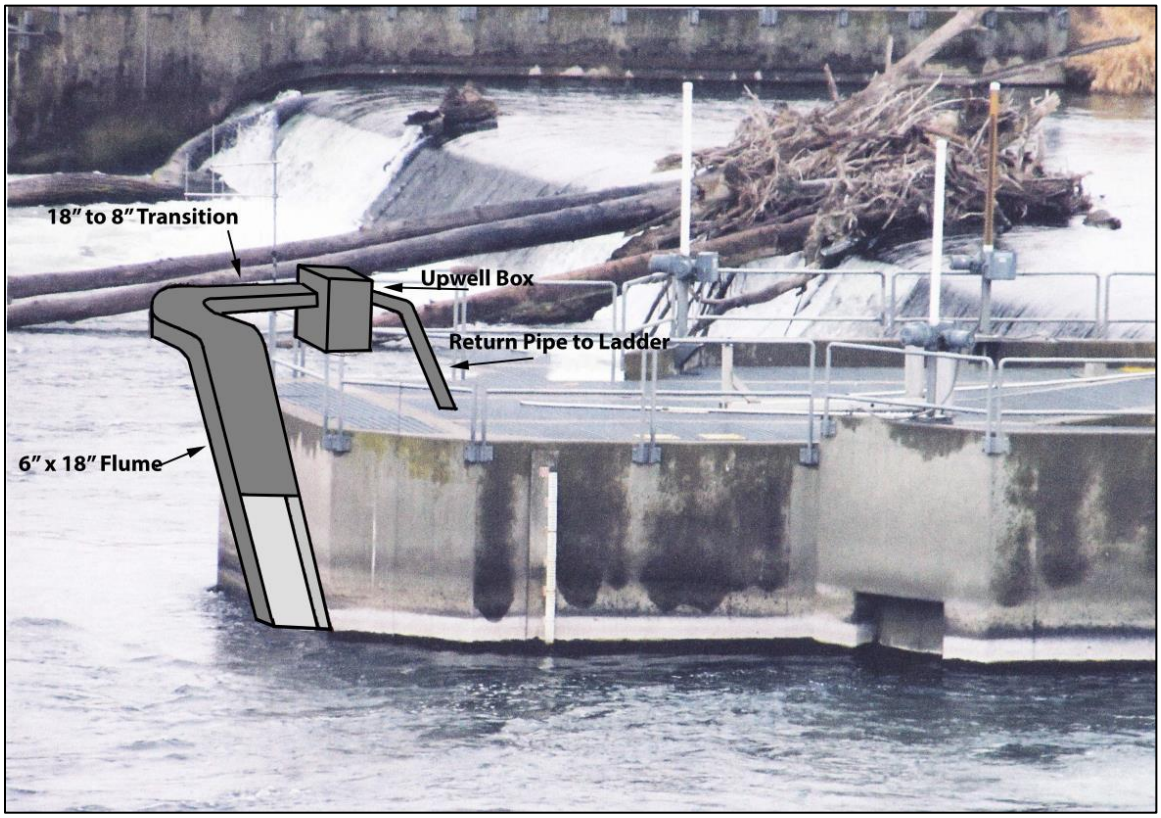

Figure 25. Photograph of the center fishway at Sunnyside Dam with concept drawing of LPS that returns lamprey into the fish ladder (J. Simonson, Fishhead Technology and Mark Nelson USFWS).

Figure 26. Photograph of center fishway at Sunnyside Dam with concept drawing of LPS that returns lamprey to river upstream of dam instead of into fish ladder as shown in Figure 25 (J. Simonson, Fishhead Technology).

Spawning

Spawning areas of Pacific lamprey in the Yakima River basin have not yet been definitively identified. No entries into Ahtanum Creek (a short distance upstream of Wapato Dam) were detected despite the availability of likely spawning areas and the presence of larval Pacific lamprey and western brook lamprey *Lampetra richardsoni* (Reid 2012; Patrick Luke, Yakama Nation, pers. comm.). During Phase 2, some tagged lampreys moved upstream as far as rkm 53 in the Naches River before overwintering. They moved back downstream in the Naches River varying distances during the following summer- behavior consistent with probable spawning-related movements that were noted during a telemetry study in the John Day River (Bayer et al. 2000). However, no tagged lamprey have been documented spawning in the Yakima River basin.

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